FINAL REPORT

Application of the SEBAL Methodology for Estimating Evapotranspiration and Consumptive Use of Water Through Remote Sensing

Phase IV:

Refinements in an Operational System

Idaho Department of Water Resources
and
University of Idaho

Submitted to

The Raytheon Systems Company
Earth Observation System Data and Information System Project

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1.0 Executive Summary

Mapping EvapoTranspiration with High Resolution and Internal Calibration (METRIC)
METRIC is a satellite image-processing model for computing evapotranspiration for large areas based on satellite image-data, in this case Landsat. It computes a complete radiation and energy balance for each pixel. METRIC evolved specifically for the western United Stated from the more general ET model, SEBAL.

Linkage Among Phases I, II, III, and IV
The linkage among the first three phases of Synergy is the common need for an inexpensive, accurate, and quick way to map evapotranspiration over large areas in Idaho.

Objectives for Phase IV
Phase IV had four objectives. The first objective was to expand the application and validation of METRIC to non-agricultural land cover types, particularly residential and rangeland. The second objective was to validate the preliminary ET values for the land use/land cover types of the Boise Valley that were generated from Phase III data. The third objective was to validate the version of METRIC ported to IDRISI. The fourth objective was to convince water users and Idaho decision makers to jointly fund the annual use of METRIC as a water administration tool. The first three objectives were achieved. The fourth objective remains a challenge, especially in a period of dramatic state budget cuts.

User Community
The user community is the Idaho Department of Water Resources (IDWR), and other water organizations such as the U.S. Bureau of Reclamation, canal companies, irrigation districts, and other water measurement organizations.

New Product Development
Research personnel at the University of Idaho have expanded the METRIC model to include non-agricultural land.

Web Development
The part of the IDWR Synergy project website has received 56,834 user sessions between January 1, 2003 and November 30, 2003. The existing IDWR/Synergy web site was augmented 1) to make the site 508 compliant; 2) consolidate all ET applications into a single application; and 3) add a pixel-value read-out used by passing the cursor over the image.

Lessons Learned
First, old data do not always support new uses. In this case, METRIC is suitable for operational use, but the supporting water-rights data are not. Second, a state

agency with operational responsibilities that are defined in statute will not change its business processes to depend on non-operational data sources.

Potential Activities for Phase V
Activities will take three directions: 1) transferring RS and GIS technology to local water delivery organizations; and 2) exploring the relationship between the MODIS ET product and METRIC; and 3) working with the USBR to integrate METRIC into their western water decision support systems.

Publications
Ten publications resulted from Phase IV, including two Ph.D. dissertations.

Presentations
Eight presentations were made at professional symposia.

Student Involvement
Synergy Phase IV supported three Ph.D. students, with two degrees awarded; two Master's students; and one Bachelor's student

2.0 Introduction

2.1 Background

Synergy phases 1, 2, and 3 are linked in that each is a further evolutionary step aimed at the operational use of a Landsat-based, energy-balance evapotranspiration model in the Idaho Department of Water Resources.

Overall objective for phase 1 was to test a Landsat ET model and evaluate whether or not it might have potential for application for the Idaho Department of Water Resources. The results of the comparison with SEBAL and lysimeter-measured ET were encouraging, and some initial modifications were made to SEBAL to make it more applicable to the intermountain western U.S.A.

Overall objective for phase 2 was to test the model in a more demanding environment by moving the test area to the area of greatest agriculture, the ESRP, testing the model against more lysimeter data, and make any necessary adjustments to the model. SEBAL results matched lysimeter ET very closely, and researchers at the University of Idaho made significant modifications to SEBAL in order to make it easier to run and more accurate.

Overall objective for phase 3 was to demonstrate operational applications of the model to the Idaho Department of Water Resources, and further refine the configuration of the model. The tests demonstrated that SEBAL could be used operationally. Additional modifications made by the University of Idaho researchers made to the model made it significantly different from the original SEBAL.

The overall objective of phase 4 was to expand the use of SEBAL. The model was further refined. Discussions with the developer of SEBAL, Dr. Wim Bastiaanssen, resulted in a decision to reserve the term “SEBAL” of the original model, which is still being run, and the renaming of the University-of-Idaho version to “METRIC”

2.2 SEBAL and METRIC

For four years, the Idaho Synergy project has tested, applied and developed SEBAL. Before the first Synergy application in Idaho in 2000, SEBAL had not been used in North America. In no small part because of the ET activities funded under Synergy, SEBAL has received sufficient attention that it is now a viable commercial product. The commercial market for SEBAL is being served by a company in California under an agreement with Dr. Bastiaanssen.

Throughout the history of the Synergy project, researchers at the University of Idaho have made extensive modifications to the original SEBAL algorithm to fine-tune the model for the semi-arid climate of Idaho and to take advantage of the extensive ground weather data available in the western United States. As a result, the original SEBAL code has been concomitantly modified.

As a result of the commercialization of SEBAL and of the extensive modification of both the original SEBAL algorithm and code, an agreement has been struck between the University of Idaho and WaterWatch that reserves the use of the term “SEBAL” to WaterWatch and its business partners. Therefore, the University of Idaho has chosen to use the term “METRIC” for the version of the ET model being used in the Synergy project. “METRIC” stands for **M**apping **E**vapo**T**ranspiration at High **R**esolution with **I**nternal **C**alibration. This report will refer to the ET model used as “METRIC”.

2.3 Objectives of Phase 4

IDWR had four main goals for Phase 4. All four goals are focused on integrating METRIC into the management activities of water-resource agencies in Idaho at the federal, state, and local levels. The goals are listed below.

1) Expand the application and validation of METRIC to non-agricultural land cover types, particularly residential and rangeland.

2) Validate the preliminary ET values for the land use/land cover types of the Boise Valley that were generated from Phase III data.

3) Validate the version of METRIC ported to IDRISI.

4) Convince water users and Idaho decision makers to jointly fund the annual use of METRIC as a water administration tool.

These goals were defined in January, 2003. Work to achieve the goals was hampered by the funding process imposed by NASA. Initial work authorization was granted on March 3rd for 60 days only. On April 30th, the period of performance was extended to Feb. 28th, 2004, with funding authorized through August 31, 2004. this contracting structure effectively prevented IDWR and UI from beginning work until April 30th. By statute, IDWR cannot enter into a contract with a subcontractor if a funding mechanism is not in place. Since the initial project funding was only for 60 days, IDWR personnel were prohibited from executing the contract with UI. The nature of the proposed work did not lend itself to this piecemeal approach.

3.0 User community

Several IDWR business processes have used METRIC ET, and two of them are using ET operationally. Other, potential users include USBOR and local water delivery organizations.

3.1 The Idaho Department of Water Resources

METRIC is being applied operationally by two, and has the potential to be used by two others. The first IDWR business processes that uses METRIC ET is the Water Planning Bureau. Potential operational uses at IDWR are in Water Allocation Section, which administers water rights, and Water Distribution Section, which is charged with monitoring ground water withdrawals.

3.1.1 Operational Use by IDWR

The Water Planning Bureau is using METRIC as the source of ET that is input to a hydrologic model being run to help time irrigation withdrawals to mitigate effects on endangered species. In the second application, the Hydrology Section is using METRIC as the source of ET for building water budgets for hydrologic models, and as a measure of aquifer depletion.

The Water Planning Bureau is implementing MIKE BASIN, a water routing model, to help assure adequate water to support endangered anadromous fish in the streams of the upper Salmon River watershed. The MIKE BASIN model is a proprietary software package written and sold by DHI Water & Environment, a Denmark-based non-profit organization. MIKE BASIN is a network model implemented as an extension to ArcView. It's inputs include time-series data on runoff, meteorology, irrigation requirements, and return flows.

IDWR is in the third year of this program. The first year was supported by the U.S. Bureau of Reclamation, while the second and third years also received funds from the Bonneville Power Administration. During 2003, the third year of model operations, USBR contributed $80,000, and the Bonneville Power Administration contributed $30,000.

The Hydrology Section is using METRIC as the source of ET and depletion for the IDWR hydrologic models. The grid cells of the Eastern Snake Plane aquifer model (ESPAM) are shown superimposed on an image of seasonal ET in Figure 1a. figure 1b is an enlargement of four of the cells. Before the advent of METRIC ET, the ESPAM used ET derived from an "irrigated" class in a land cover theme, a nominal breakout of crop types, and nominal crop-type ET coefficients. The ET value that resulted from this process was somewhat crude and of uncertain accuracy. The variability is actual ET versus the nominal ET as represented by a crop coefficient is well illustrated by Figure 2 .

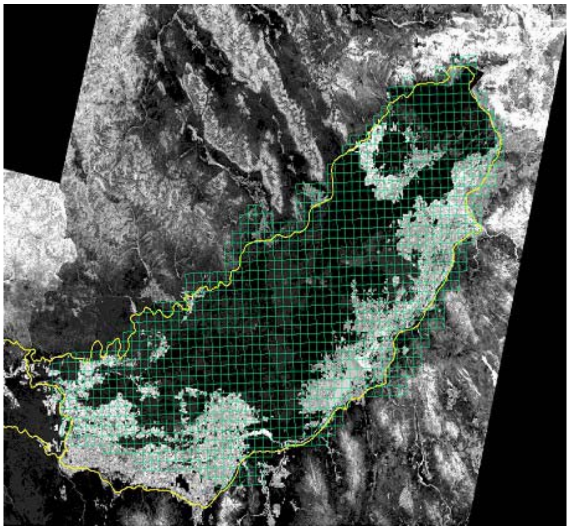


Figure 1a. Grid cells of the Eastern Snake Plane Aquifer Model on an image of seasonal ET.

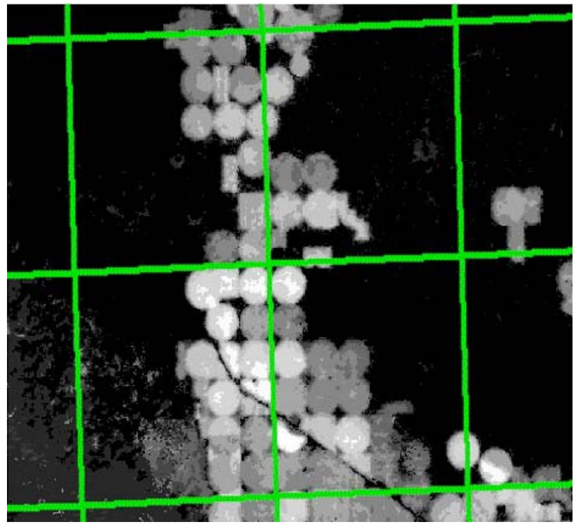


Figure 1b. Four grid cells of the Eastern Snake Plane Aquifer Model, on top of an image of seasonal ET.

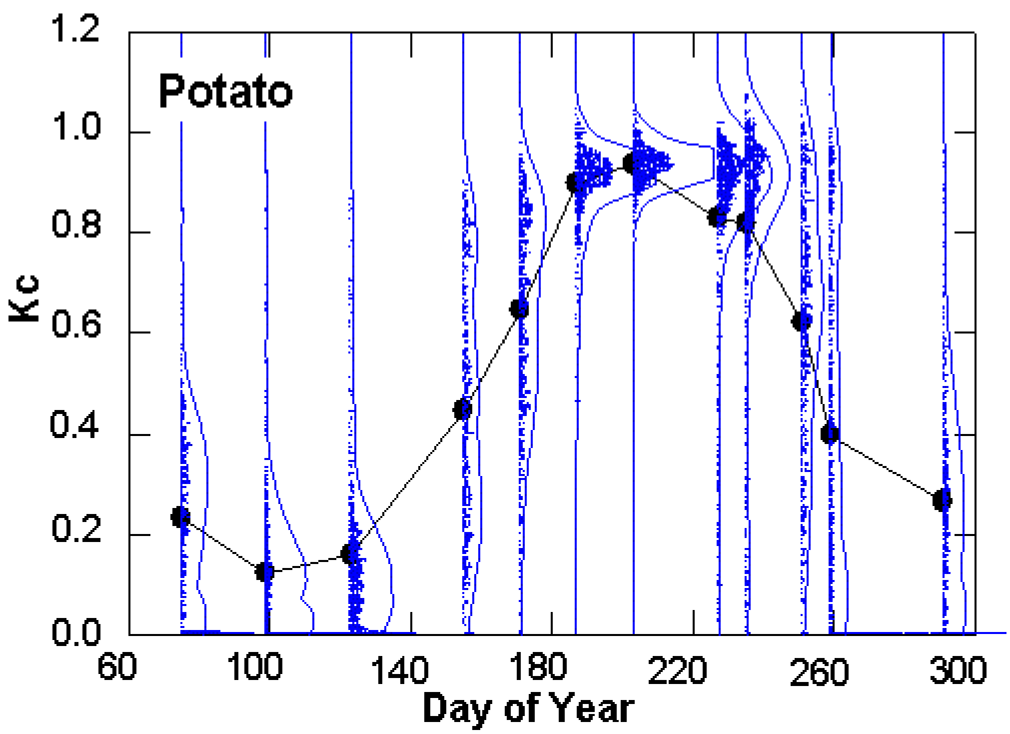


Figure 2. Crop coefficients determined by METRIC from 717 potato fields in the Twin Falls area of Idaho for 12 Landsat image dates during 2000 (solid line is the mean). *From Allen, et al., 2003*.

3.1.2 Potential Operational Use by IDWR

Two IDWR business processes have potential uses for METRIC ET. The potential uses are in Water Allocation Section, which administers water rights, and Water Distribution Section, which is charged with monitoring ground water withdrawals. The utility of METRIC ET has been demonstrated, but several barriers prevent those groups from immediately adopting METRIC.

METRIC ET is operational in Hydrology and Planning but not yet for water-rights related business processes because for Hydrology and Planning, ET is a direct input to a business process, while for water-rights business processes, ET is not a direct input. Use of ET by water-rights related business processes will require significant changes in the actual business process. Personnel are reluctant to change familiar processes for unfamiliar ones.

For Hydrology and Planning, their business processes use ET as an input to their business processes. The source of the ET has no direct impact on the core function of those business processes. The lack of direct impact means that those business processes have a lot of flexibility in how they generate ET. Thus, they can adopt a METRIC-based ET product without any adverse impact.

On the other hand, for Water Allocation and Water Distribution to replace their existing methods with ET requires a significant commitment to change. The actual processes by which those personnel do their jobs has to change, and the cost of that commitment is a much higher than it is for Hydrology and Planning.

The other important barrier to acceptance of METRIC is the tenuous status of Landsat. Without the reasonable assurance of data continuity at an inexpensive cost, no changes will be made.

3.2 Other Potential Users

3.2.1 Local Water Delivery Organizations

Work with the locals requires starting from scratch. They need to be trained in how remote sensing and GIS apply to their particular issues and circumstances. The only organizations we deal with are ones that have shown a willingness to make a commitment to using the technology.

Before local organizations can use tools like METRIC they need to be able to use a basic tool of spatial analysis: ArcView. IDWR will do the METRIC processing for the locals, they will never do that processing themselves. Beyond their scope, beyond the experience level of their employees, and they don’t have the time. Figure 3.2.1-1 is a map showing the local water delivery organizations with which IDWR is working as of December 1, 2003.

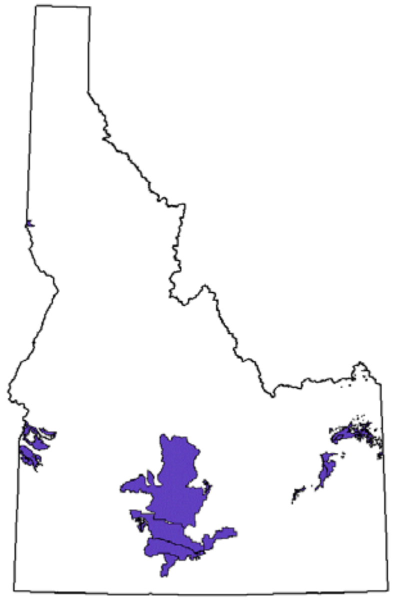


Figure 3.2.1-1 Map showing the local water delivery organizations with which IDWR is working as of December 1, 2003.

3.2.2 The Bureau of Reclamation

The U.S. Bureau of Reclamation has two potential areas of involvement. First, they want to support on-going programs to increase the efficiency of water delivery by expanding the use of remote sensing and GIS in the local water delivery organizations. Second, they want to evaluate the potential benefits of using METRIC produced ET mapping in their decision support systems for water management in the Western United States.

To meet these ends, USBR has undertaken two actions. First, they entered into a cooperative agreement with IDWR to provide software to the local water delivery organizations. IDWR, in turn, provides data and support. Second, USBR has committed to evaluate METRIC ET from both Landsat and MODIS.

3.3 User Requirements and Expectations

3.3.1 Local Water Delivery Organizations

Before 2003, all the Local Water Delivery Organizations (LWDOs) in Idaho use paper maps and user inventories. Beginning in January, 2003, IDWR and USBR began working with some LWDOs in a pilot project to upgrade the LWDOs to use remote sensing and GIS technology. The motivation on the part of the LWDOs is cost reduction. They want to know where their water is going, and whether their water is being diverted by anyone not paying an assessment. They want to have up-to-date maps and inventories of their water delivery infrastructures to facilitate infrastructure maintenance. Several LWDOs have decided to put water delivery data on the internet in order to allow irrigators to inquire directly about the availability their water allocation. This reduces the amount of LWDO staff time spent answering these inquiries.

The overall strategy used to bring the LWDOs on board is to work intensively with a few motivated organizations, get them working well, and let them convince other LWDOs about the benefits of using remote sensing and GIS. This is a peer-to-peer strategy.

Actual implementation has four parts. First, the LWDOs are given the text Getting to Know ArcView, and given time to study it. Second, IDWR personnel travel to the LWDOs to conduct a two to three day workshop during which ArcView (provided free by USBR) is installed, LWDO personnel are trained, and the appropriate data are installed. Third, further site visits are made as necessary to assist the LWDOs in data conversion and training in more advanced methods of dealing with water-right data, tax parcel data, and other specialized data. Fourth, IDWR provides telephone support as needed.

3.3.2 Bureau of Reclamation

USBR intends to conduct its assessment in two phases. The first phase, beginning in Fiscal Year 2004, will be conducted through its current technology transfer initiatives. The second phase will be a more extensive assessment and development in Fiscal Year 2005 with funding from internal USBR programs.

4.0 Product Development:

Developments to METRIC have been designed to extend METRIC from agricultural land to non-agricultural land. The precursor to METRIC, SEBAL (as well as the early incarnations of METRIC) was designed specifically for agricultural land. In Phase 1, IDWR testing of SEBAL involved grass hay. The application of the ET model to similar, wild vegetation was therefore always in mind. The need for applying METRIC to built-up land cover types came during the period of Phase 3, but was actually form a separate IDWR business process that was not part of the Synergy project. The Water Planning Bureau needed as estimate of the amount of ET by land use/land cover class for the Boise Valley.

The Boise Valley in southwestern Idaho has a semi-arid climate with approximately 20 to 30 cm of precipitation per year. It is approximately 415,000 hectares in size. The predominant land uses are irrigated agriculture (41%), urban and built-up (10%) and rangeland (32%). The average annual precipitation in the valley is approximately 30 centimeters. The predominant land use type has been agriculture, with approximately 370,000 irrigated hectares.

Over the last 20 years, the valley has grown in population from 257,000 in 1980 to 431,000 in 2000. An important issue facing water planners is water availability in a valley that is changing from mostly agricultural land-use to more urban types of land use. Department planners have gained insight into the issue by combining land use/land cover (LULC) polygons from aerial photograph interpretation, and METRIC-derived ET, both for the year 2000. Seasonal evapotranspiration was generated for the period March 15, 2000 to October 15, 2000. The product was an “image” of seasonal evapotranspiration. LULC polygons were overlaid on the evapotranspiration image and the mean evapotranspiration was computed for all polygons of each LULC class.

The purpose of this project was to compute the amount of ET by LULC to allow the planners to understand how the demand for water will be affected by the transition of land from irrigated agriculture to residential, commercial, and industrial LULC types.

Preliminary analysis indicates there is some error associated with ET for residential land use, but that the maximum error is relatively small. A reasonable approximation of the maximum error induced by the differences is 1.5 mm per day at peak summer temperatures. In terms of the total seasonal ET, the error in the urban classes is probably between 15% and 20%. A second potential source of error, exclusive of METRIC, stems from omission and commission errors in the land use/land cover classification. Therefore, work was proposed to 1) design a version of METRIC that would be more accurate for non-agricultural land, and 2) quantify the classification accuracy.

4.1 Product Description

4.1.1 METRIC Modifications for Non-Agricultural Land (From Allen, et al., 2004)

For the past three years the interest in METRIC application has been primarily focused on agricultural areas, as it is water resources applied to these areas that is of most current immediate concern to IDWR. Recent research focus by University of Idaho has been to further improve and test METRIC for city (commercial and residential) and desert settings to reduce uncertainties in ET predicted for these land-use types.

4.1.2 Product Need

The need for extending METRIC to non-agricultural areas was motivated by the desire of the IDWR planners to quantify ET by land use/land cover type (Morse, et al., 2003). METRIC was developed for agricultural applications. Applying METRIC to non-agricultural land cover meant some error in the ET computation. The error was estimated to be approximately 15% over an entire growing season (Allen, personal communication). This product is an effort to reduce that error, and improve the extension of METRIC to non-agricultural land.

4.1.2.1 METRIC Application for City Areas

4.1.2.1.1 Model Development History

During METRIC development in Idaho (Morse et al., 2000, 2001 and 2002), agricultural settings were the primary focus of model development and applications. The current version of METRIC estimates ET from city area relatively well. Typical ET_rF (fraction of reference evapotranspiration) for Twin Falls, a major city in southern Idaho, is 0.1 for commercial/industrial and 0.4 for the residential areas, indicating that water consumption is only 10 to 40% as much as a fully vegetated agricultural field. However, these estimates have some uncertainty, as the assignment of values for surface roughness length (z_{om}) for city areas in METRIC had some uncertainty and impact prediction of sensible heat and ET (Tasumi, 2003).

In Phase 1 of the Raytheon-IDWR application (Morse et al., 2000), z_{om} was estimated as a function of normalized difference vegetation index (NDVI), following the SEBAL procedure of Bastiaanssen et al. (1998). This procedure is based on the commonly used morphometric approach, which estimates z_{om} as proportional to the height of obstacles (Grimmond and Oke, 1999). NDVI was used as an indicator of the height of obstacles in SEBAL. This assumption is somewhat reasonable for agricultural settings, but fails in city areas where NDVI and the obstacle height are not related. One problem in this method was that very small roughness values are assigned for city areas having low NDVI values. Thus city area were treated as very smooth surfaces, causing underestimation of the mechanical transfer of heat and overestimation of ET.

In Phases 2 and 3 (Morse et al., 2001 and 2002), z_{om} was assigned values using landuse maps for areas other than agricultural fields. The use of landuse maps improved z_{om} and ET estimations for these nonagricultural areas. In these studies, city areas were assigned a fixed z_{om} of 0.5 m. The z_{om} value was determined from a height-based equation with empirical multiplier for agricultural crops 0.12 (Allen et al., 1996). The mean height of obstacles (i.e. buildings, trees, etc.) were estimated not by NDVI but by manually assigned values.

4.1.2.1.2 Review of Roughness Estimation in Urban Areas

Currently there exist two major approaches for estimating roughness (z_{om}) of city or urban areas: morphmetric (or geometric) and micrometeorological (or anemometric). The morphmetric approach includes height-based methods, height and “plan aerial fraction (λ_p)” based methods, and height and “frontal area index (λ_f)” based methods. These morphmetric methods do not require meteorological measurements from tall towers, and this is their primary advantage (Grimmond and Oke, 1999). λ_p is the ratio of obstacle area to the total city area, and λ_f is the ratio of average “frontal” area (i.e. area or cross-section of obstacles normal to the horizontal wind direction) of obstacles to the total city area. Figure 1 shows the conceptual relation between z_{om} and λ_p or λ_f.

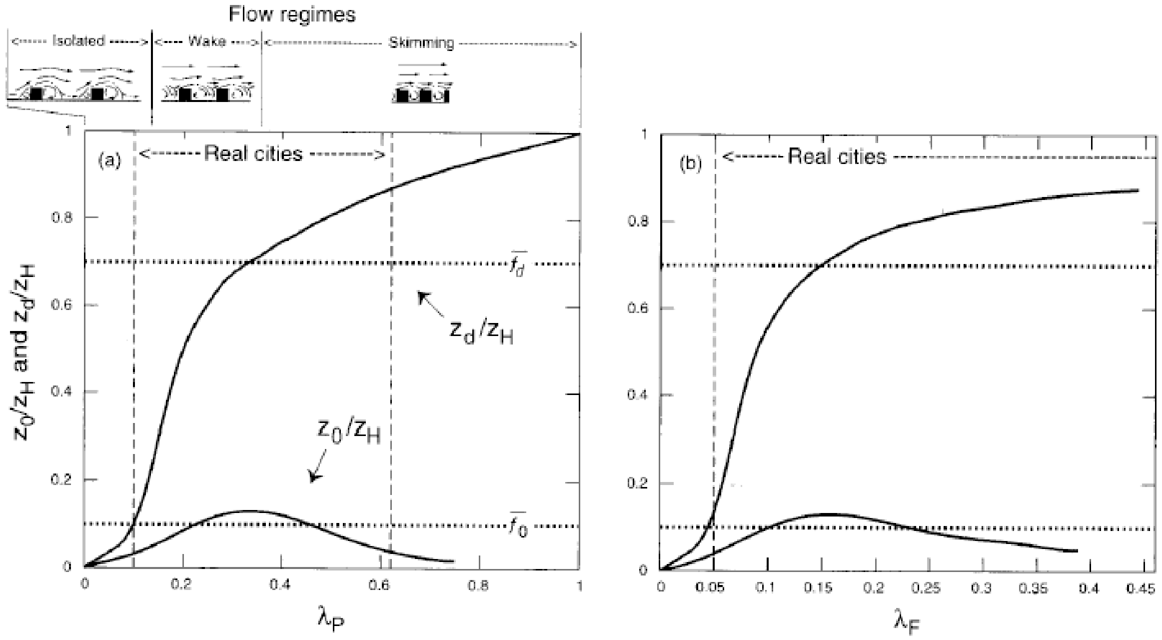


Figure 4.1.2.1.2-1. Conceptual representation of the relation between height-normalized values of d (d/h) and z_{om} (z_{om}/h), to λ_p and λ_f. Source: Grimmond and Oke, 1999

Micrometeorological methods theoretically estimate surface roughness using anemometers. Roughness is derived from a measured vertical wind profile or windspeed at one level with a standard deviation, or through direct measurement of wind using fast response anemometer (Grimmond et al., 1998). In either case, a tall tower is required to measure windspeed and can not be affected by individual obstacles.

4.1.2.1.3 Investigated Procedures for Roughness Estimation in METRIC

We have investigated the following three alternative approaches for estimating z_{om} for cities:

(A) Values determined from literature

Recommended city roughness values can be found or determined from literature, stemming from previous studies. This is the easiest way to determine roughness values, especially when a previous study has focused on the city in question.

(B) Height-based methods

Height-based methods can simply specify a value for z_{om} for a city area based on mean heights of buildings and other obstacles. The estimated value will be less accurate than that obtained from method C. The operator must determine surface roughness of the city area from the obstacle height. A widely used method is to apply a coefficient found by Hanna and Chang, 1992:

$$z_{om} = 0.1 * \text{height} \qquad (1)$$

(C) Plan aerial fraction (λ_p) based method

The plan aerial fraction based method is well fitted to remote-sensing/GIS applications such as METRIC. Many METRIC operators already have necessary information for applying the plan aerial fraction based method. This method was investigated in this phase of the Raytheon-IDWR project to improve surface roughness values and subsequent ET estimation for cities.

Application of the plan aerial fraction based method for determining city z_{om}

Twin Falls is the largest city along path40/row30 of Landsat. Surface roughness length was estimated using a plan aerial method for commercial/industrial and residential zones of Twin Falls. Per Grimmond and Oke, 1999 , obstacle classifications for wind were restricted to those for buildings, trees and large shrubs. Smaller obstacles (e.g., traffic signs, fences, other garden plants, etc.) were neglected. Grimmond and Oke noted that placing these restrictions results in a bias toward an underestimation of roughness properties. Buildings and trees have very different impact on the air stream, especially in that wind can flow through trees while buildings prohibit wind penetration. In this study, areas of trees were adjusted assuming a 0.2 porosity, following Grimmond and Oke, 1999, Heisler 1984; and Heisler and DeWalle, 1988. Then, z_{om} was determined by plan aerial fraction as described in these previous studies and summarized by Grimmond and Oke (1999) (figure 4.1.2.1.3-1).

Since convenient GIS information on building polygons was not available for the city of Twin Falls, GIS data were created using air-photos for selected typical commercial/industrial and for residential areas of Twin Falls. Figures 4.1.2.1.3-2 and 4.1.2.1.3-3 show the commercial/industrial and residential selected areas.

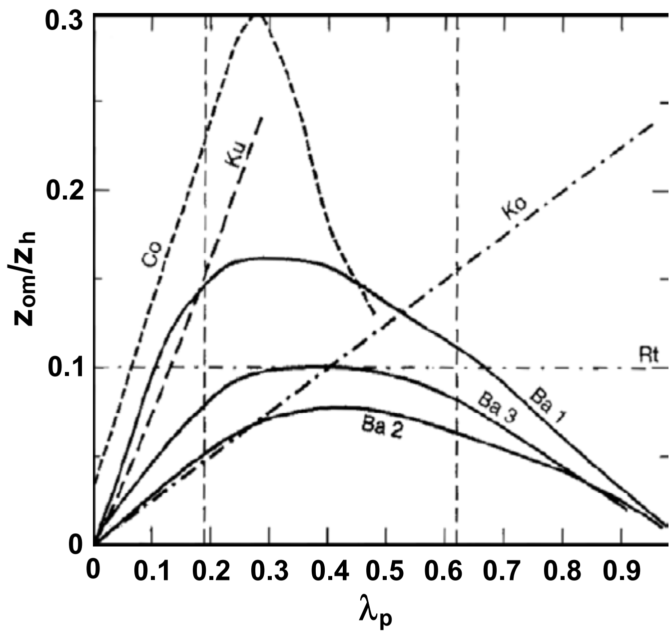


Figure 4.1.2.1.3-1. Sensitivity analysis of plan aerial fraction method to determine z_{om} normalized with respect to mean element height z_h, done by Grimmond and Oke, 1999. Studies evaluated were Kutzbach (Ku), 1961; Counihan (Co), 1971; Kondo and Yamazawa (Ko), 1986; Bottema (Ba), 1995. The frequently referred "Role of thumb" (Rt) is $z_{om}/z_h = 0.1$.

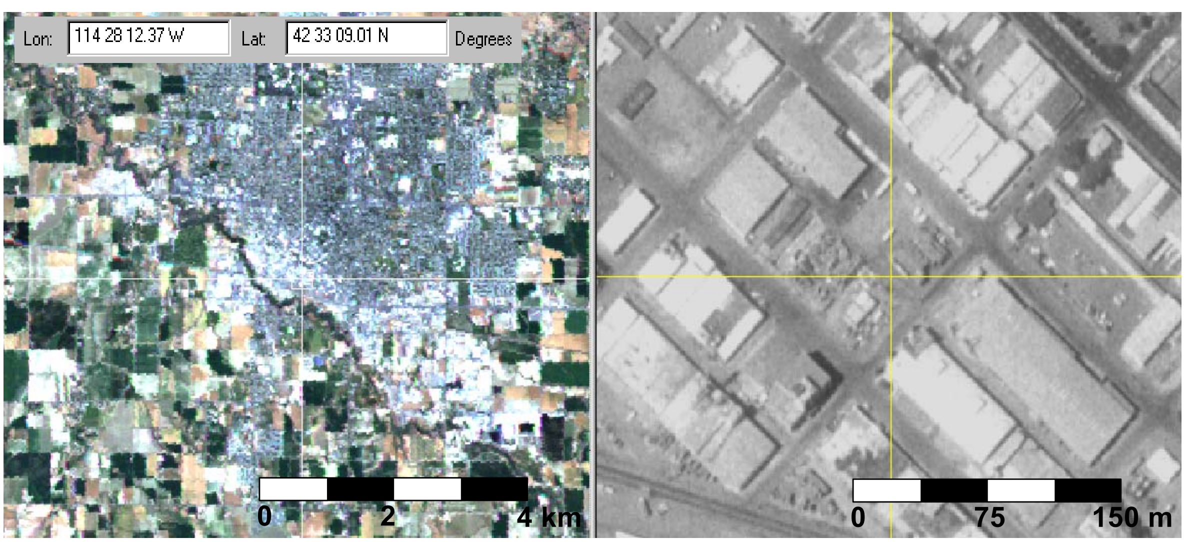


Figure 4.1.2.1.3-2. Typical Commercial/Industrial Area in Twin Falls (true color on left) and aerial photo of city center on right (cross hairs intersect a common area)

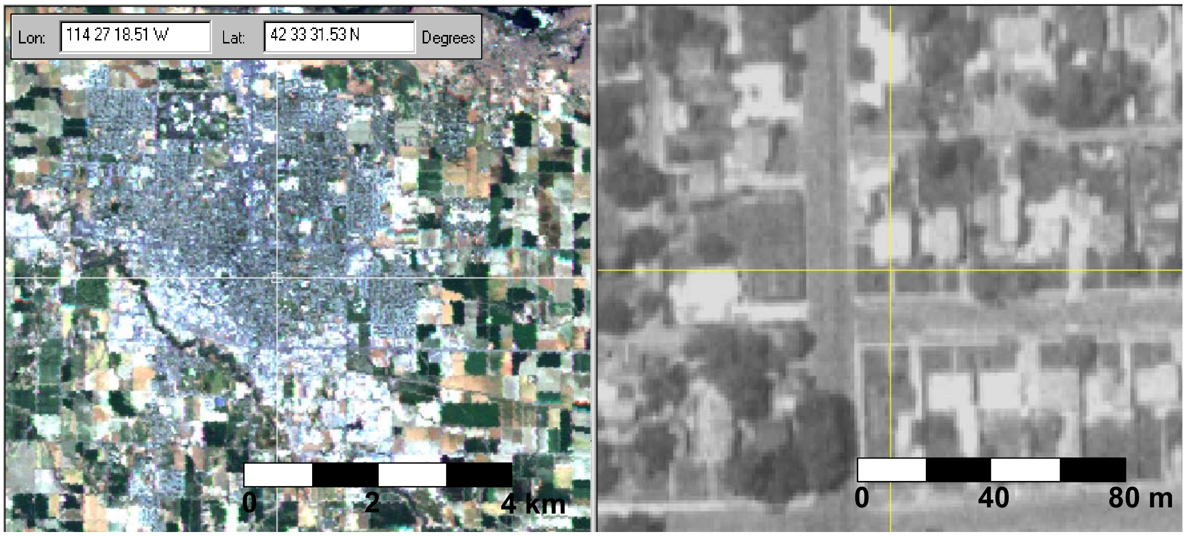


Figure 4.1.2.1.3-3. Typical Residential Area in Twin Falls (true color on left) and aerial photo of city center on right (cross hairs intersect a common area)

4.1.2.1.4 Commercial/Industrial Area

The selected commercial/industrial area totaled 99,416 m^2 and contained 43054 m^2 of and buildings, so that λ_p was 0.433. Previous studies (figure 4.1.2.1.3-1) have indicated that a ratio of z_{om}/z_h for λ_p=0.433 to be between 0.08- 0.15. Thus, for the above λ_p and assuming a z_{om}/z_h ratio of 0.1 and an average height of obstacles (z_h) of 7 m, the z_{om} calculated for the Twin Falls industrial area was 0.7 m.

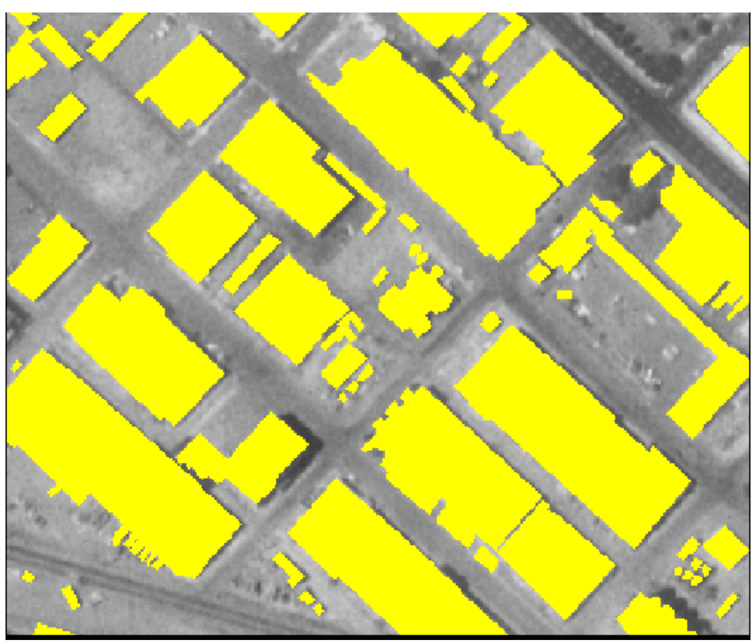


Figure 4.1.2.1.4-1. Air-photo of commercial/industrial area in Twin Falls city. Identified buildings are colored as yellow.

4.1.2.1.5 Residential Area

The selected residential was 16,297 m^2 and contained buildings totaling 5,245 m^2 in area. The total area of trees was 3,543m^2, which is equivalent to 2,834 m^2 of building area after adjustment for porosity. The calculated λ_p was 0.322. For this level of λ_p, the majority of the z_{om}/z_h ratios in previous studies (figure 4.1.2.1.3-1) is in the range of about 0.08-0.15. In the residential area, z_{om}/z_h ratio is very similar to that for the commercial/industrial area, although the λ_p was quite different. This discrepancy can be attributed to the effect of density on the z_{om}/z_h ratio shown in Figure 4.1.2.1.3-1. If the z_{om}/z_h ratio is assumed to be 0.1, and the average height of obstacles is assumed to be 7 m, z_{om} is calculated as 0.7 m. Thus, the estimated z_{om} for commercial/industrial and for residential areas was the same.

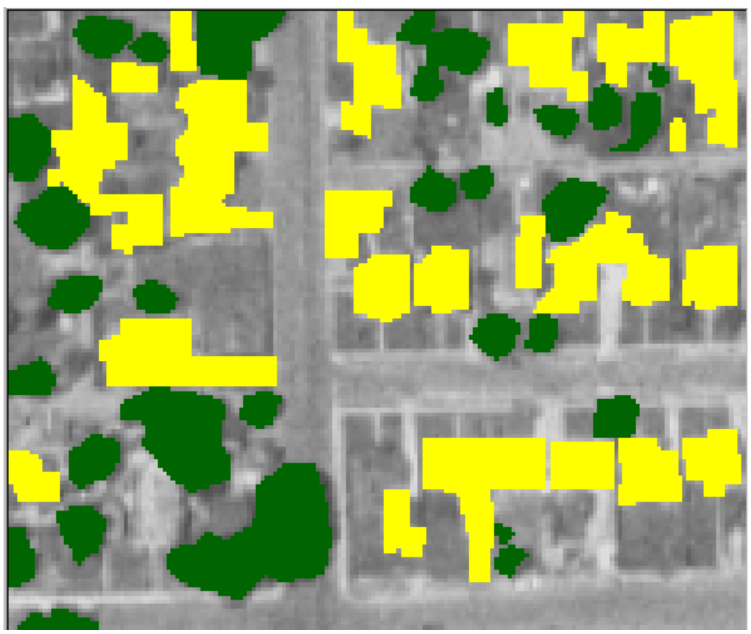


Figure 4.1.1.2.5-1. Air-photo of a residential area in Twin Falls city. Buildings are identified and colored as yellow, trees are green.

4.1.2.1.6 Application Results

Estimated roughness by air-photo and the other studies was 0.7 m, which is somewhat higher than the value of 0.5 m used in previous applications of METRIC in Idaho. Figure 4.1.2.1.6-1 shows a sensitivity analysis of ET_rF from METRIC for Twin Falls city. By revising z_{om} from 0.5 to 0.7 m, ET_rF changed by only 0.03 under very dry conditions

(ET_rF ~ 0), and with almost no impact under moderately wet conditions (ET_rF ~ 0.4) typical of residential areas. This trend is confirmed in figure 4.1.2.1.6-2, which shows ET_rF maps computed assuming z_{om} = 0.5 and 0.7 m. It is worth mentioning that negative ET_rF numbers appear in some commercial/industrial areas. METRIC renders negative ET_rF results in these areas since an average z_{om} value was applied to the entire city. This indicates that values of ET for specific pixels are not reliable in city areas because ET for pixels having roughness smoother than the average is underestimated, and vice versa. The average or accumulated value for ET for the city area is considered to be more reliable. The revised z_{om} value provided for a realistic ET map for most of the year 2003 images as shown in figure 4.1.2.1.6-2. The plan-aerial fraction method investigated will allow METRIC users to optimize the surface roughness values for their own urban settings.

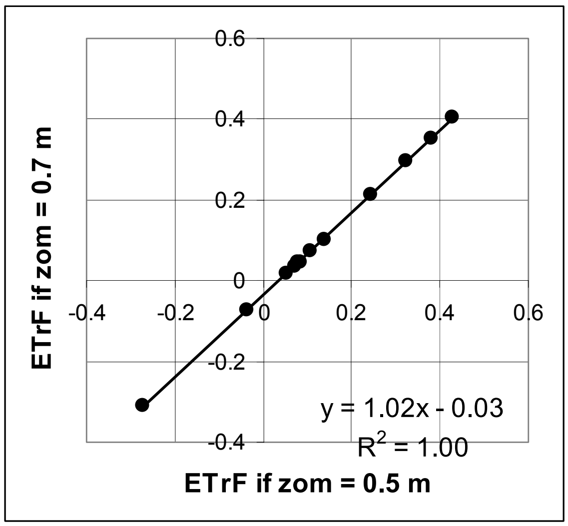


Figure 4.1.2.1.6-1. METRIC ET_rF for Twin Falls, Idaho, applying z_{om} = 0.5 m and applying z_{om} =0.7 m for city areas on 8/14/2000.

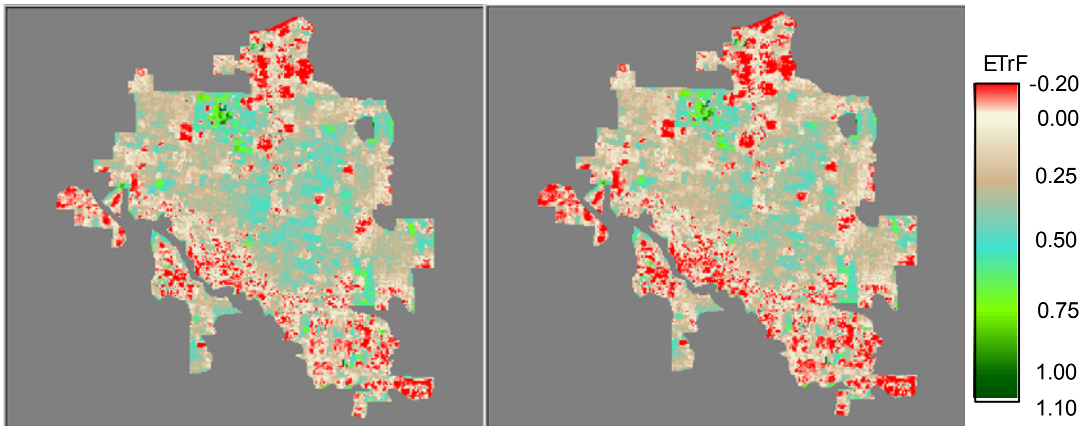


Figure 4.1.2.1.5-2. Twin Falls city area: false color Landsat image (above), estimated ET_rF assuming z_{om} = 0.5 (left) and ET_rF assuming z_{om} = 0.7 (right), 8/31/2003.

While estimated ET values appear to be realistic for most of the year 2003 images processed, ET was poorly estimated on three high-wind dates. On these three dates, ET from some city areas was assigned large negative values. This underestimation is due to overestimation of sensible heat flux densities (H). One reason for the error might be from prediction of near-surface air temperature gradients (dT) using information based on agricultural settings. Under calm wind conditions, this might not cause problems because the heat transfer from dry and rough city areas such as industrial areas and dry and smooth agricultural fields (used to assign the "hot pixel" of METRIC) are relatively similar since mechanical effects of heat transfer are small and buoyancy effects dominate. On strong wind days, mechanical transfer by wind drives the majority of surface-air heat transfer, and therefore rough city surfaces and smooth agricultural surfaces behave very differently even though both surfaces are dry. These large differences predicted for H confuse energy balance estimation in city areas. Improvement in the air temperature gradient (dT) estimation is one of the next topics of the METRIC model improvement.

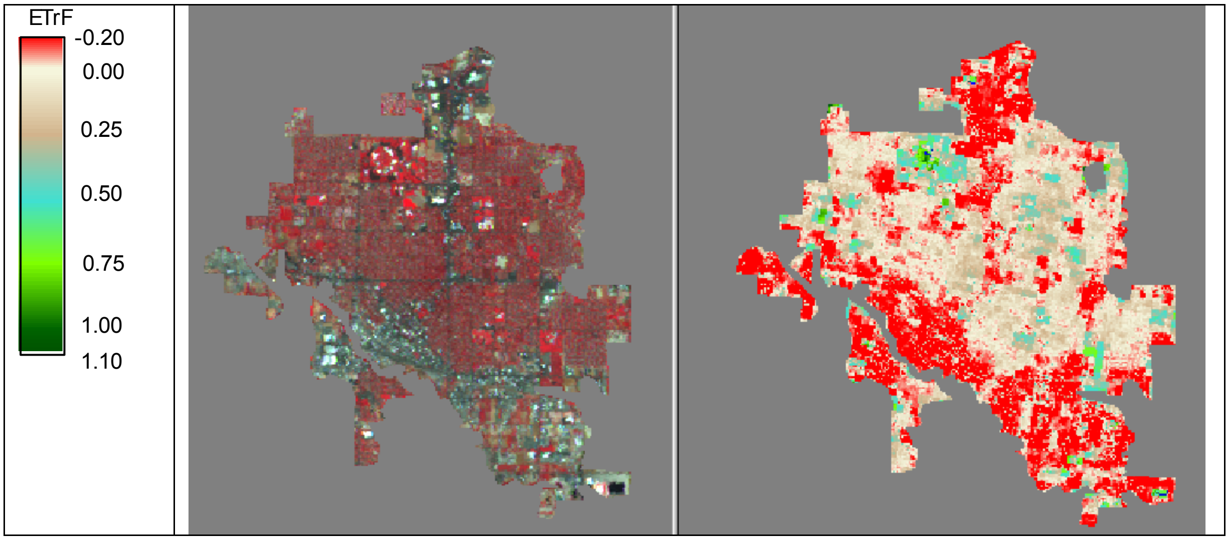


Figure 4.1.2.1.6-3. Example of negative ET estimation on high-wind dates, 6/28/2003, u_{200} = 8.97 m/s.

4.1.2.2 Improvement of Estimation Accuracy in Desert Environment

4.1.2.2.1 Background

In METRIC, sensible heat flux density (H) is estimated using a near-surface air temperature gradient (dT) estimated from surface temperature (T_s) observed by satellite and using aerodynamic resistance for heat transfer (r_{ah}) computed via an iteration process for air stability correction based on Monin-Obukhov similarity theory:

$$H = \frac{\rho_{air} C_p dT}{r_{ah}} \quad (2)$$

where ρ_{air} is air density (kg m^{-3}), C_p is the specific heat capacity of air (≈ 1004 J kg^{-1} K^{-1}), r_{ah} is aerodynamic resistance to heat transport (s m^{-1}), dT is the near surface to air temperature difference, predicted between a height near the surface (0.1 m above the zero plane displacement height) and a height at about 2 m above the surface. Parameter r_{ah} is surface roughness determined through iteration for air stability correction by applying Monin-Obukhov similarity theory (Bastiaanssen, 2000).

METRIC systematically overestimates sensible heat and underestimates ET for some southern Idaho desert areas. A plausible cause for such behavior is the influence of sage brush and tall grass vegetation that effectively protects the land surface from mechanical heat transport (i.e., wind), but is sparse enough to permit the penetration of incoming solar radiation that heats the soil surface. This combination of permitting solar radiation penetration but inhibiting wind penetration, makes the surfaces of some desert areas sensed by the satellite extremely hot. Therefore, METRIC assigns large values to the sensible heat flux density by assuming large vertical air-temperature gradients and strong buoyancy of air corresponding to the extreme surface temperature according to Monin-Obukhov similarity theory.

Ultimately, the systematic overestimation of H needs to be more closely investigated and solved in a theoretical manner. In the mean time, an empirical correction has been explored where we add an extra resistance, r_{extra}. Incorporating the extra resistance, the estimated H equation becomes:

$$H = \frac{\rho_{air} C_p dT}{r_{ah} + r_{extra}} \qquad (3)$$

where r_{extra} is empirical extra resistance for Idaho desert conditions.

4.1.2.2.2 Data Correction

Sensible heat flux density measurements have been gathered since July 2003 at a site in the southern Idaho desert using a sonic 3-dimensional anemometer manufactured by Campbell Scientific (CSAT3). The instrument sonically measures windspeed and the speed of sound on three nonorthogonal axes at relatively high frequency (10 Hz). Orthogonal windspeed and sonic temperature are computed from these measurements and sensible heat is obtained by correlating fluctuations of vertical wind speed with fluctuations of the transported scalar of heat (via eddy covariance).

The sonic instrument was installed in a desert setting at 42º 57' 6.02" north and 113º 42' 8.48" west (figure 4.1.2.2.2-1). This location is in the overlapping area of Path 39 and 40 Landsat images, enabling satellite image availability to double for analysis. Besides the 3-dimensional sonic anemometer (CSAT3), the desert weather station (figure 4.1.2.2.2-2) included an air temperature and relative humidity probe (HMP45C), two Apogee infrared thermometers with one directed toward the soil surface temperature and the other directed toward a sage brush canopy, a solar pyranometer, and four thermocouple thermometers at various heights for measuring the vertical air-temperature gradient. Windspeed and sonic temperature were measured at 0.1 second intervals, and all other data were measured at 1 second intervals. Fifteen minute averages for data were calculated and stored in the Campbell 23X data logger. Examples of collected data are presented in figure 4.1.2.2.2-3.

According to Twine et al. (2000), there is a tendency for eddy covariance based on sonic anemometer systems to under measure sensible heat flux density. Additional instruments such as a Bowen ratio system, a net radiometer and a soil heat flux plate will be installed during spring 2004 to evaluate measurement accuracy of the eddy covariance system, as well as helping to complete a full energy balance at the measurement site.

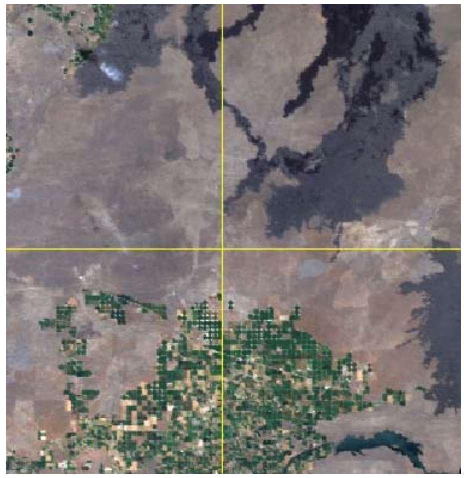


Figure 4.1.2.2.2-1. Location of the University of Idaho sonic anemometer station on a true-color Landsat image from path 40/row 30.

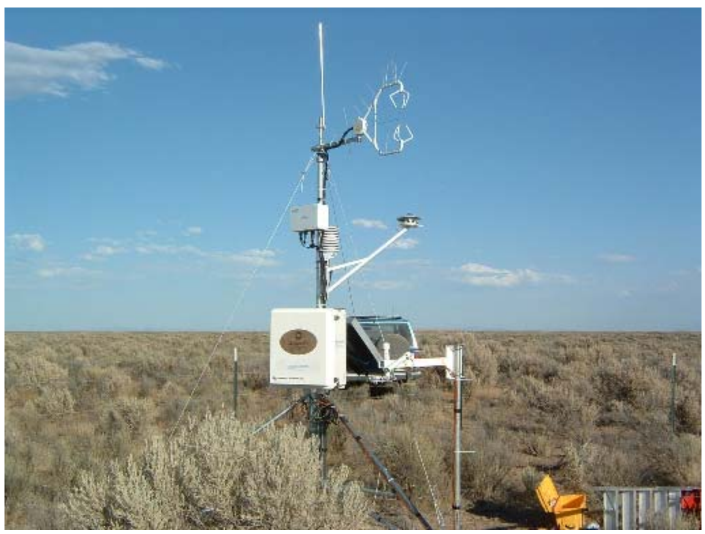


Figure 4.1.2.2.2-2. University of Idaho three-dimensional sonic anemometer station.

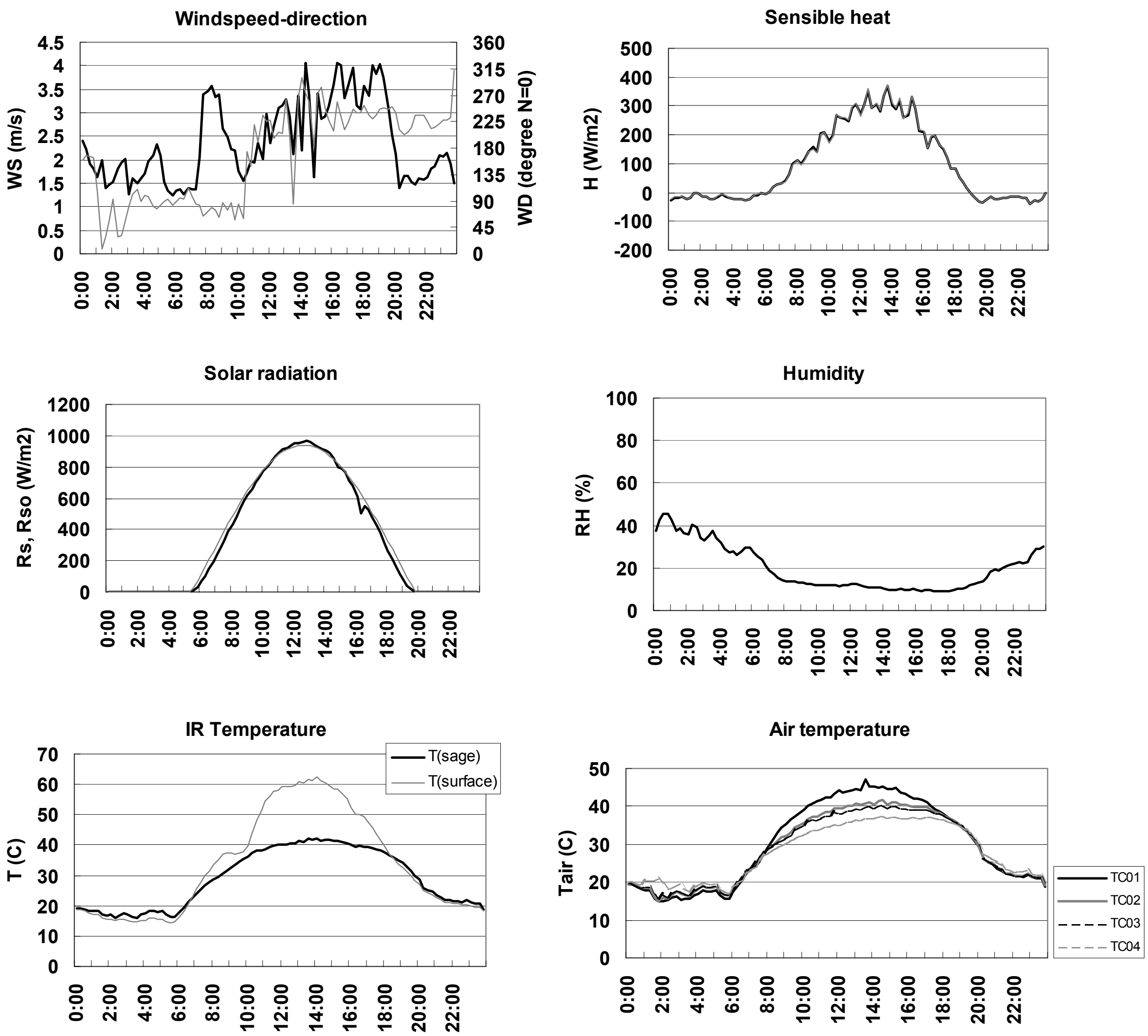


Figure 4.1.2.2.2-3. Example meteorological measurements from the University of Idaho desert station on 7/30/2003. The data include vertical wind speed and direction, sensible heat flux density, solar radiation, relative humidity, desert soil and vegetation surface temperature, and vertical air temperature profile determined at four heights 2cm/20cm/40cm/230cm above the ground surface.

Three satellite images, two from path 40 and one from path 39, were obtained for the period when ground measurement data were available. Seventeen other images from 2000 and early 2003 were additionally evaluated and used to supplement the analysis (tables 4.1.2.2.2-1 and 4.1.2.2.2-2).

Table 4.1.2.2.2-1. Year 2003 Landsat images analyzed during the analysis. The last three dates (7/30, 8/24 and 8/31) had meteorological data collected at the university desert station.

Date	Satellite	Path/Row
4/9/03	Landsat 5	40/30
5/19/03	Landsat 7	40/30
5/27/03	Landsat 5	40/30
6/28/03	Landsat 5	40/30
7/14/03	Landsat 5	40/30
7/30/03	Landsat 5	40/30
8/24/03	Landsat 5	39/30
8/31/03	Landsat 5	40/30

Table 4.1.2.2.2-2. Year 2000 Landsat images used to supplement the analysis.

Date	Satellite	Path/Row
3/15/00	Landsat 5	40/30
4/8/00	Landsat 7	40/30
5/2/00	Landsat 5	40/30
6/3/00	Landsat 5	40/30
6/19/00	Landsat 5	40/30
7/5/00	Landsat 5	40/30
7/21/00	Landsat 5	40/30
8/14/00	Landsat 7	40/30
8/22/00	Landsat 5	40/30
9/7/00	Landsat 5	40/30
9/15/00	Landsat 7	40/30
10/17/00	Landsat 7	40/30

4.1.2.2.3 Analyses to Determine Values for Extra Resistance

METRIC was applied to images from July and August 2003, which is a period when the ground measurements were available. In the applications using no extra resistance, METRIC estimation of H was always higher than the sonically measured values, as expected. The overestimation was between 11-13% for 7/30 and 8/24 images, and nearly 60% for the 8/31 image (table 4.1.2.2.3-3, figure 4.1.2.2.3-1). The METRIC estimation for H became nearly identical to measured values when an extra resistance was applied that made ET estimated from extremely hot desert conditions (generally hotter than measurement site) become zero (table 4.1.2.2.3-3, figure 4.1.2.2.3-1).

Table 4.1.2.2.3-1. Measured and METRIC estimated sensible heat flux densities for the measurement site location. “METRIC with extra resistance” used an extra resistance that made ET for an extreme desert condition to be zero.

Date	Path	H (from sonic) W/m^2	H (from Metric with no adjustment) W/m^2	Difference %	H (from METRIC with extra resistance) W/m^2	Difference %
7/30/2003	P40	257	286	11.3	247	-3.9
8/24/2003	P39	237	267	12.7	-	-
8/31/2003	P40	228	359	57.5	224	-1.8

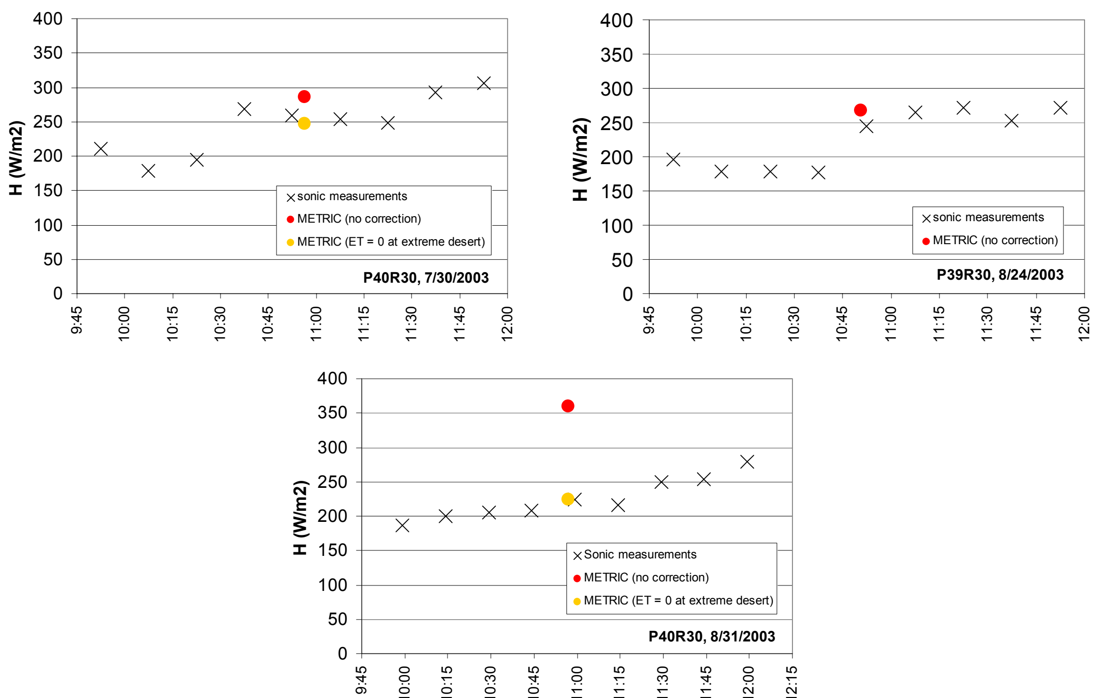


Figure 4.1.2.2.3-1. Measured and METRIC estimated sensible heat flux density for the measurement site on 7/30, 8/24 and 8/31/2003. “METRIC (ET = 0 at extreme desert)” was applied using an extra resistance that made ET for an extremely hot desert condition become zero. This condition was not considered for 8/24/2003 because the image had a significant rainfall few days prior and therefore the desert area may have had some residual moisture.

Values for extra resistance were calculated for all other available images from 2000 and 2003 under the assumption that the appropriate value for extra resistance is the amount needed for ET from extremely hot desert areas to become zero. We found the calculated r_{extra} to have strong dependency on winds peed (figure 4.1.2.2.3-2).

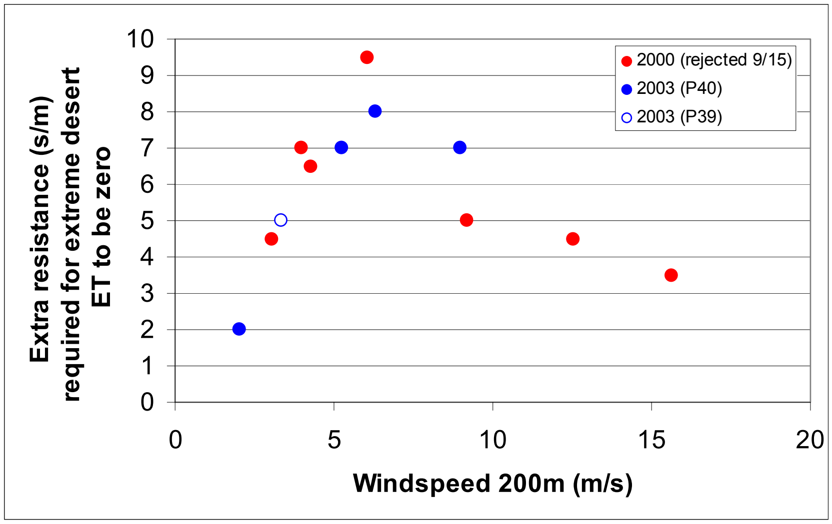


Figure 4.1.2.2.3-2. Required extra resistance in METRIC as a function of wind speed at 200 m height.

The relationship between r_{extra} and wind speed reflects either the failure of assumptions in METRIC, for example, in the calculation of friction velocity (u_*) or that predicted air-temperature gradient have a problem (e.g. u_* might be overestimated due to the "sheltering effect" of the desert vegetation), or failure of Monin-Obukhov similarity theory for extreme desert conditions. Both of these reasons have the same result as described in the following. However, in either case, applying r_{extra} during the METRIC processing appears to be an effective way to tentatively solve the problem and thus improve the desert ET estimation.

The required value for r_{extra} is small at low wind speeds because the heat transfer is dominated by buoyancy and is thus essentially independent of surface roughness. At high values of wind speed, the required value for r_{extra} is again small because of more effective penetration of wind to the soil surface within the sparse vegetation and subsequent surface cooling. The cooler surfaces result in prediction of smaller values for dT and thus H. It is the middle range of wind speed (3 to 10 m s^{-1} at 200 m height) that require the most adjustment via r_{extra} due to the larger impact of sheltering of the surface.

The mechanism for generating a universal trend between r_{extra} and wind speed is complicated because of the interdependencies between u_*, rah and the air temperature gradient (dT), as air-stability correction affects all of these terms.

A sensitivity analysis of estimated r_{ah}, dT and H for different wind speed levels conducted for the hot pixel of METRIC (a dry agricultural bare field) and for an extremely hot desert condition as shown in figures 4.1.2.2.3-3 and 4.1.2.2.3-4, illustrates the phenomenon more clearly. At the hot pixel, H is computed as the residual of the energy balance and therefore its value does not change for different wind speed levels. However, the corresponding values for r_{ah} and dT do change because different wind speeds, given a fixed value for H, produce different intensities of mechanical and buoyancy induced heat transfer. Values for dT and r_{ah} linearly correspond at the hot pixel because H is fixed (equation 2). On the other hand, for the extremely hot desert area (figure 4.1.2.2.3-4), calculated r_{ah} decreases as wind speed increases due to the effect of wind speed, while dT takes on a parabolic shape because dT at any satellite pixel is estimated using dT information in METRIC at the hot agricultural pixel, which has parabolic shape. These two terms tend to make H a parabolic function of wind speed.

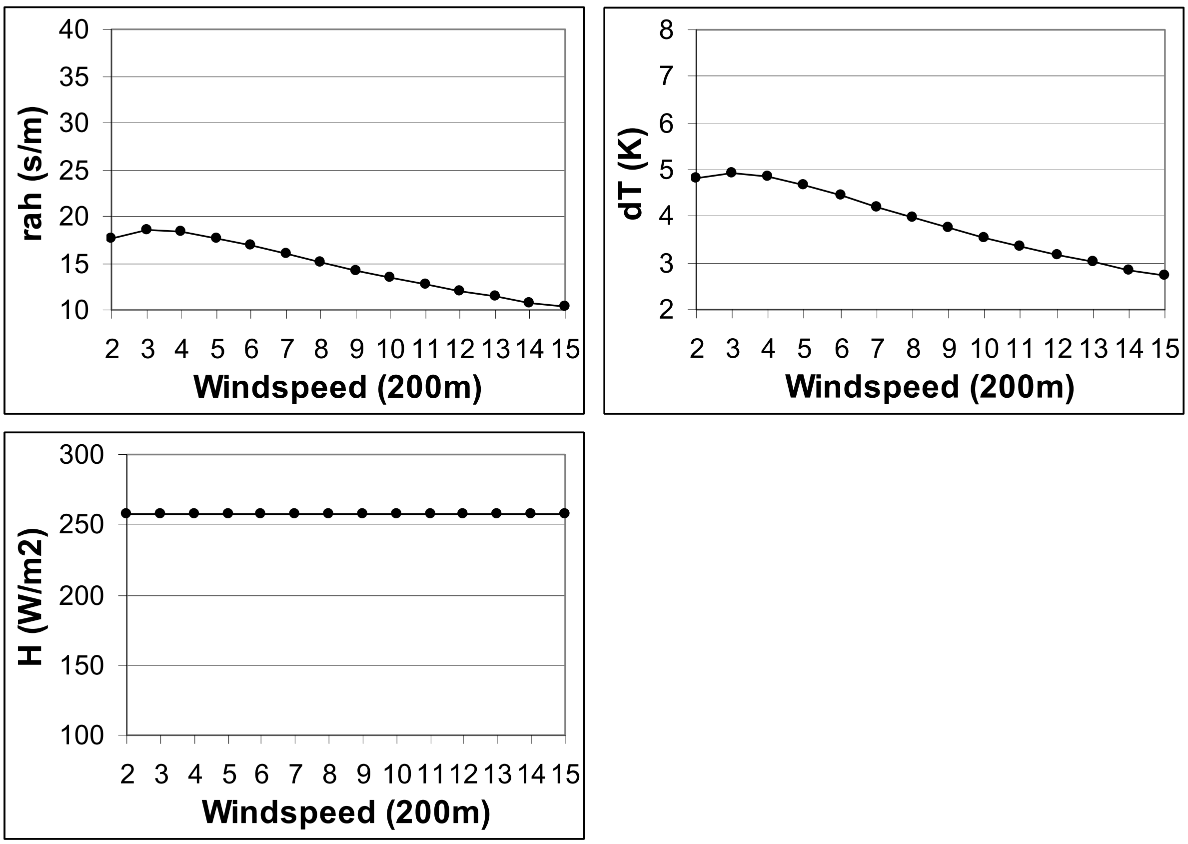


Figure 4.1.2.2.3-3. Sensitivity of r_{ah}, dT and H, for different windspeed levela at the selected hot pixel (dry agricultural bare field) in Path 40 Row 30, 7/5/2000.

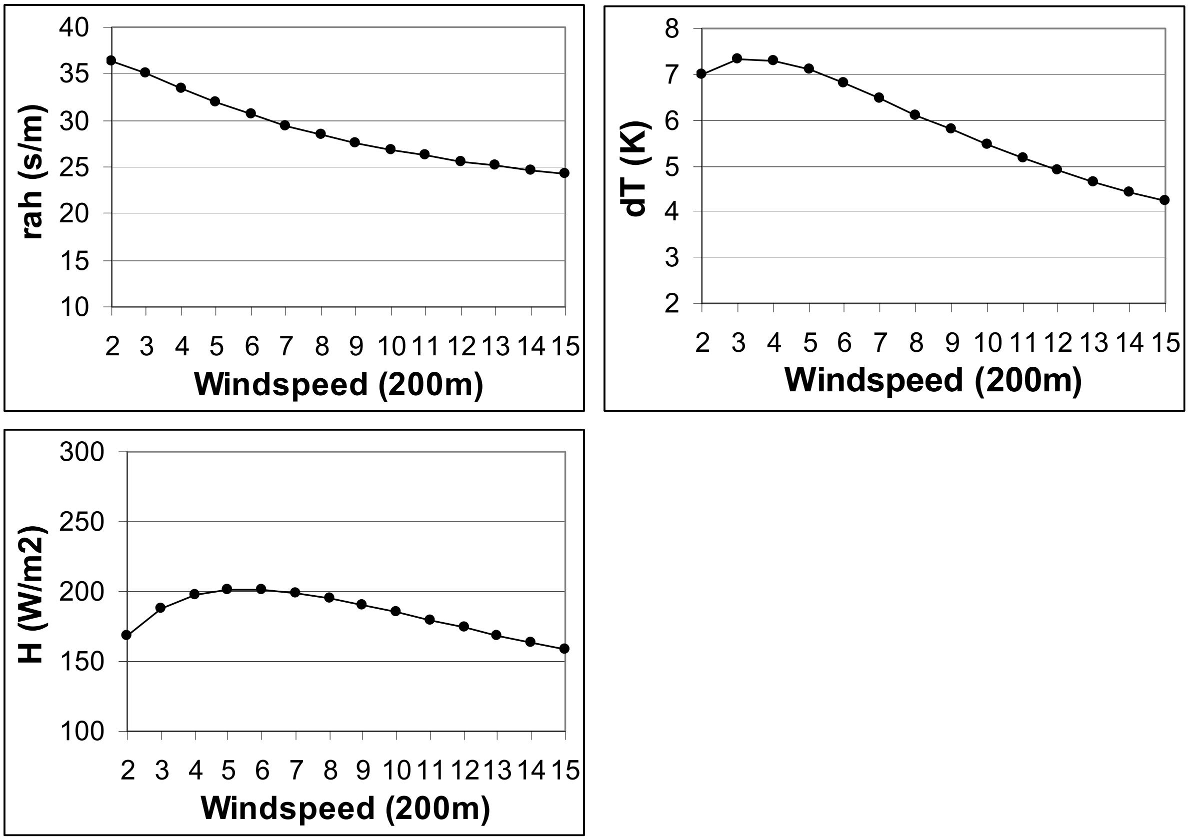


Figure 4.1.2.2.3-4. Sensitivity of r_{ah}, dT and H, for different windspeed levels at an extremely hot desert location in Path 40 Row 30, 7/5/2000.

The extra resistance values based on H measured by the sonic system caused some desert sites to have unreasonably large ET. This may indicate that we overcorrected aerodynamic resistance, since the sonic anemometer may have underestimated values for H (Twine et al. 2000). Therefore, the definition of extra resistance was modified to cause ET for average desert conditions to be zero (figure 4.1.2.2.3-5). The same trend with the windspeed resulted, but with moderated values for resistance. Figure 4.1.2.2.3-5 shows the plots of estimated r_{extra} by windspeed for 12 image dates from mid to late summer in 2000 and 2003. Two typical desert areas were selected from each image, and each point in figure 17 represents the average value from a selected desert area. The regression equation by this analysis is:

$$r_{extra} = 0.0130u^3 - 0.4351u^2 + 4.2748u - 8.2835 \quad R^2=0.61,\ n=24 \qquad (4)$$

where r_{extra} is in s/m, and u is windspeed at 200m in m/s.

Equation 4 is limited to values of wind speed less than 15 m/s (where the correction equals 2 s m^{-1}) and to greater than than 2.6 m/s (where the correction equals zero).

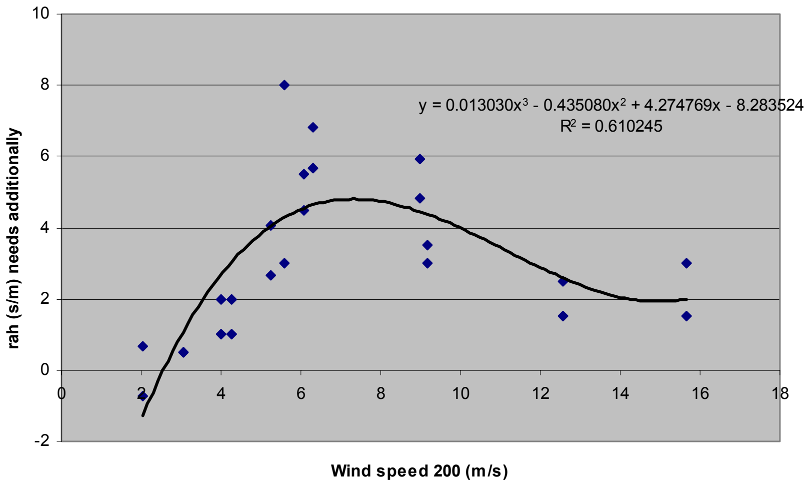
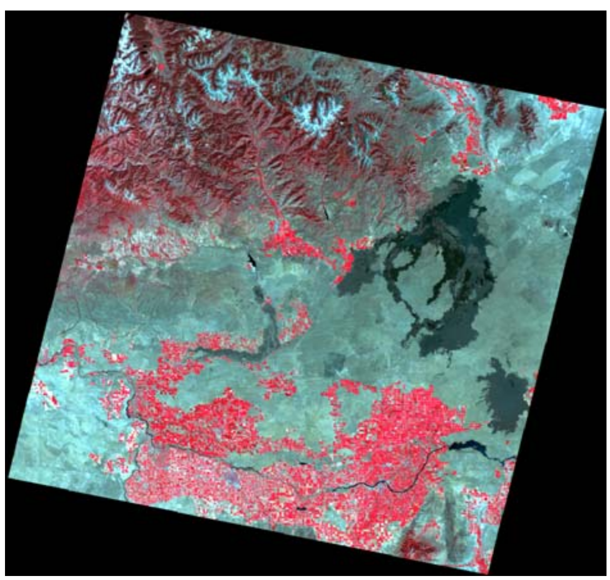


Figure 4.1.2.2.3-5. Values for extra resistance that cause ET at average desert locations to be zero in mid to late summer.

By applying the determined extra resistance, desert ET estimation was improved as shown in figure 4.1.2.2.3-6. In figure 4.1.2.2.3-6, most of the desert areas previously had negative ET, which is incorrect. After applying the extra resistance, ET from most desert areas averaged zero, which is expected in mid July in southern Idaho, when the soil profile is very dry.



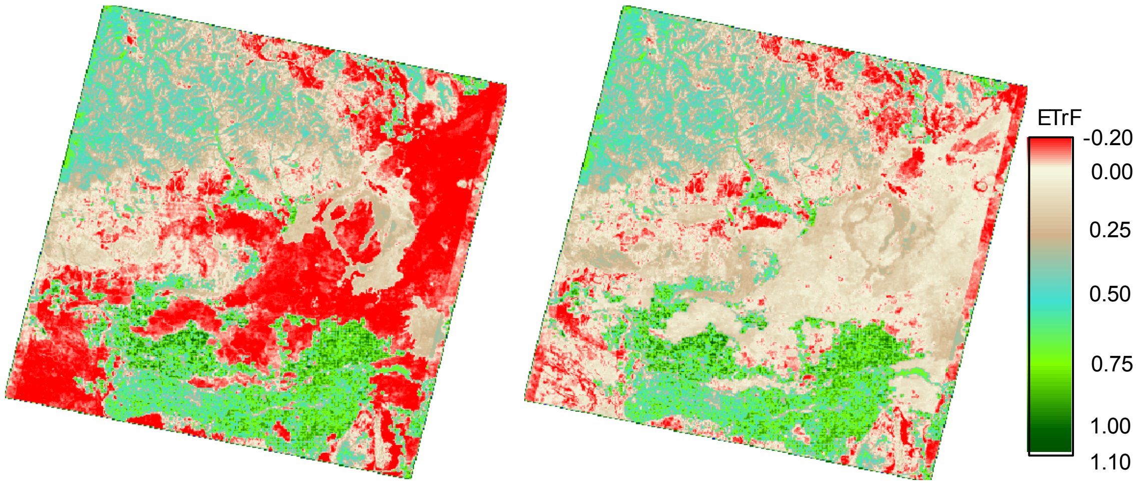


Figure 4.1.2.2.3-6. Landsat false color image and ETrF by METRIC before and after adjustment using the extra resistance term for 7/14/2003.

A progression of sensible heat flux density measured by the sonic anemometer system and as predicted by METRIC with and without an extra resistance is shown in Figure 4.1.2.2.3-7 for the measurement period.

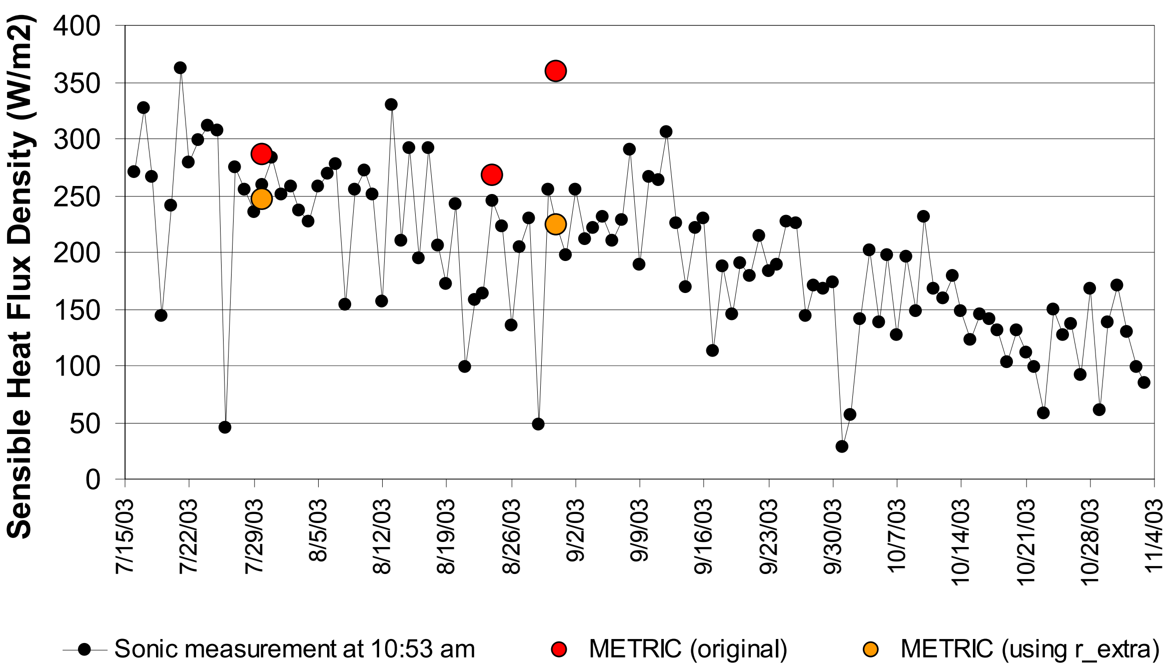


Figure 4.1.2.2.3-7. A progression of sensible heat flux density measured by the sonic anemometer system and as predicted by METRIC with and without an extra resistance.

4.1.2.3 Determination of Water Consumption in Magic Valley, Idaho for 2003.

Seven Landsat images for path 40/row 30 were processed during 2003 as listed in Table 4.1.2.2.2-1 to determine water consumption. Monthly ET by pixel was computed along with total ET during the April to August period. Lack of cloud-free Landsat 5 images during September and October precluded processing for this period. The monthly and seasonal ET data are being utilized by IDWR for water rights management, hydrologic modeling and assessment of mean water consumption by crop.

4.1.3 Accuracy Evaluation for Boise Valley Land Cover
From Lifton, 2003

4.1.3.1 Product Need

This study was designed to quantify the omission and commission errors in the Boise Valley Land cover classification. The purpose of the evaluation was to quantify the categorical errors that would lead to errors in the computation of ET for a LULC class.

4.1.3.2 Description

The purpose of reviewing the images and shapefile was to identify incorrectly classified polygons (errors of commission) and unclassified polygons (errors of omission). To keep track of these, two fields were added to the attribute table for the shapefile. One field is for new polygons, labeled “New”, and the other is for incorrect polygons, labeled “Incorrect”. These fields are single integers, and are automatically assigned a value of zero (0).

Aside from technical obstacles, one of the greatest difficulties encountered in this accuracy assessment was pinning down working definitions of each class. Definitions of each class, created during the original classification, were provided. However, many cases do not fit neatly into these definitions. For example, two types of rural residences are defined as the following: Residential – Rural: “Rural residential is open, very light density residential. Lots are generally between one and five acres;” and Residential – Farmstead: “Farmsteads are homes, generally isolated from other residences, associated with agricultural fields. This includes vegetable gardens, yards, barns, other out-buildings, and storage areas.” Not all cases are described by these two definitions, and a spectrum of possibilities exists.

Other Agricultural Land (code 28) is defined as “agricultural land not otherwise described.” This became somewhat of a “garbage can” category that was used when nothing else was sufficient. Using it as such was within the limits of the definition, however there can be quite a lot of variability involved. In some cases, the line between Other Agricultural Land (code 28) and Rangeland (code 3) became blurred. Another problematic definition is found with Barren Land (code 6). It states that “areas that have been scraped bare by heavy equipment should be called Land in Transition (code 24).” However, there are several cases in which land is being cleared by heavy equipment but not is not intended for housing, as Land in Transition (code 24) implies.

Preliminary analysis of the accuracy evaluation indicates that 155 polygons out of a total of 21,442 were flagged as misclassified. This is a low error rate that is not entirely surprising due to 1) the classification was done by image interpretation on 1:24,000-scale color infrared photography, 2) the interpreter had classified the valley in a similar manner six years previously, and 3) the area classified is local to the interpreters, and uncertain interpretation were field checked.

In any event, in order for a classification error to affect the ET for the class, the error would have to be between two LULC classes with significantly different ET. Those classes that are closely related often, but not always, have ET characteristics that are close, also. From the results of the classification verification, the main source of error in the ET computation for LULC classes is in METRIC itself.

4.1.4 Validation of IDRISI METRIC Model

4.1.4.1 Product Need

The product needed was a version of METRIC implemented in the IDRISI image processing package. IDRISI is an inexpensive package that is commonly used as a teaching tool in universities. The availability of METRIC in IDRISI could make METRIC more widely available.

4.1.4.2 Description

The METRIC was converted to IDRISI macro modeler from ERDAS in order to increase the potential user base. The IDRISI version was tested it to ensure that it produced results that were consistent with the ERDAS version. The assumption was that ERDAS produced 100% accurate results, and that any differences between the outputs were due to either transcription error that occurred during code conversion, or to differences in the software packages’ numerical precision and/or handling of numbers (e.g. scalars, matrices, etc.). A subset of Landsat ETM 7 imagery (July 4, 2000; path 41, row 30) was used to compare the results of each version. The subset was processed in both the IDRISI and the ERDAS versions of METRIC. The results of each step were compared for the entire subset and at the hot and cold pixel locations. ERDAS and IDRISI produced nearly identical results for most steps of SEBAL, and much of the variation between protocols was extremely small. There were substantial differences in the values of the soil heat flux (G), G/Rn, etrf, and et24 models. Notably, the ET_{rf} value at the hot pixel was approximately zero in ERDAS and slightly negative in IDRISI, while the ET_{rf} value at the cold pixel was ~1.055 in ERDAS and ~0.89 in IDRISI. By comparing model values for each step of both protocols, and by substituting ERDAS model outputs into the IDRISI ET_{rf} /ET_{24} model, it became clear that the difference was due to a coding error in the IDRISI ET_{rf} /ET_{24} model that caused to a systematic underestimation of ET. The coding error was identified and corrected.

Another potential problem for METRIC/IDRISI is the computer resources needed to process an entire Landsat scene in a reasonable amount of time. There are workarounds and solutions, such as deleting temporary files and intermediate images from completed models, processing only a subset of the data, or using large, fast computers with large hard drives, but the resource problems may prevent the practical application by the typical user.

4.2 Significance

4.2.1 METRIC Modifications

The significance of the modifications made to METRIC is in the reduction of error when METRIC is applied to non-agricultural land.

4.2.2 Classification Accuracy

The significance of the accuracy assessment of the year 2000 LULC classification in the Boise Valley is in understanding the second source of error in the ET computation by LULC class. The results of the assessment indicate that classification error is not a significant source of error in the final ET statistics.

4.2.3 IDRISI Verification

The significance of the IDRISI verification is uncertain. Both the University of Idaho and WaterWatch have concluded there is significant commercial potential to METRIC and SEBAL, respectively, and filed notice with the Idaho Department of Water Resources that the computer code for METRIC and SEBAL are trade secrets and therefore IDWR cannot distribute the code.

5.0 Web Page Development

5.1 Web Site Statistics

IDWR keeps track of repeat visitors only for the IDWR web site *in toto*, not by specific page. Statistics on usage for the website http://www.idwr.state.id.us/gisdata for the period 1/1/2003 through 11/30/2003 show that there were 326,478 hits from 56,834 user sessions that resulted in the download of 10,484.4 MB.

5.2 Modifications

Significant progress was made on making the web site more useful. Most of the modifications involved improvements data dissemination through ArcIMS applications, but also included analysis and modifications to achieve Section 508 compliance.

There were three major ArcIMS enhancements.

First, the capability was added to view ET by "Place of Use" to the tabular statistics served by the application.

The second enhancement was to consolidate the ET applications developed for each phase of the project. All ET images from all years now have a common lookup table and are available in a single ET ArcIMS application.

The third enhancement added the capability to click on a pixel in an ET image and see the value of that pixel. This gives individuals the opportunity to get ET data directly from the browser window, without the necessity of down-loading datasets. This capability is fully implemented at IDWR, but is not fully functional. The image data accessed by this enhancement are stored in SQL Server and are accessed through ESRI's Spatial Database Engine. IDWR personnel discovered and reported to ESRI a bug in SDE that is preventing full functionality.

The bug is that the SDE function called by the ArcIMS code returns pixel values from the first pyramid layer rather than from the full-resolution image. When ESRI fixes the bug, the capability will become fully functional.

6.0 Lessons Learned

Lesson #1: <u>Old data do not always support new uses. In this case, METRIC is suitable for operational use, but the supporting water-rights data are not.</u>

Where existing business processes are in place and are already designed to accept ET data, METRIC will become operational quickly. Conversely, when the business processes need to be reengineered, or when the data needed to support the business processes are not designed for the reengineered process, then the implementation of METRIC will wait until the business process can be modified.

A business process in which METRIC was quickly accepted and adopted as operational is hydrologic modeling. That process already used a spatial representation of ET. METRIC presented a superior (faster, cheaper, better) method of computing ET, so there was no delay in implementing METRIC as an operational tool.

On the other hand, METRIC implementation has not been immediate for water rights even though METRIC was demonstrated in an operational setting. Use of METRIC ET is not only a new technology, but the use of ET as a method for estimating pumpage and for water right administration is a new approach to these tasks. Because METRIC is a new approach, all the necessary components are not in place for state-wide application. The METRIC approach requires polygons of water right places-of-use and points of points-of-diversion by in place and operational. Full implementation of Conjunctive management of water, which is the doctrine of managing both ground water and surface water as one linked and interconnected resource, be fully implemented. This implementation will follow completion of the Snake River Basin Adjudication in 2005.

Lesson #2: <u>A state agency with operational responsibilities that are defined in statute will not change its business processes to depend on non-operational data sources.</u>

In particular, IDWR managers will not make the investment in time and money to change a business process without the assured availability of Landsat data. Landsat, specifically, is needed. Landsat has a 30-year history of regular, frequent coverage. The cost for Landsat scenes is low enough to make practical the multiple dates needed for METRIC. A critical feature of Landsat is the 30-meter pixel size, which is small enough to support analysis on fields as small as 10 acres in size. Landsat has an excellent balance between small pixel size are large area of coverage. The irrigated area in southern Idaho is approximately a rectangle of 300 miles east-west by 250 miles north-south.

Landsat has a 30-year operational history. But the recent problems with Landsat 7 and NASA's canceling the LDCM have made IDWR management profoundly skeptical about the wisdom of depending on EOS data for operational applications. Even if NASA made a firm commitment to the LDCM with a thermal band, the damage has been done. IDWR management regards the problems with Landsat 7 and the LDCM as justifying their go-slow approach to integrating the results of the Synergy Program.

7.0 Experiences of the User Community

In Phase 4, METRIC ET data have been used at IDWR. IDWR has evaluated four potential applications of METRIC ET for operational use. Those applications are as follows: 1) negotiations with other states for the allocation of water among the states; 2) monitoring pumpage by irrigation wells; 3) detection of irrigation in excess of the conditions of a water right; and 4) setting the ET component of a water budget for hydrologic modeling. Of these planned applications, hydrologic modeling has achieved the most success. The other three applications were successfully demonstrated, but have not yet been adopted as operational.

There are several different reasons for METRIC not being applied operationally by each application, and several reasons that it has been adopted for hydrologic modeling. In the cased of negotiations with other states for the allocation of water among the states, there have not been any negotiations since IDWR acquired METRIC technology. When such negotiations are restarted, METRIC ET data will play an important role in allocating unused water. For the applications monitoring pumpage by irrigation wells and detecting of irrigation in excess of the conditions of a water right, the ET aspect of the application works as advertised, but deficiencies in the IDWR water rights file need to be corrected before the applications can operational state-wide. The hydrologic modeling applications have found greater success in using METRIC operationally.

The reason that METRIC ET has been readily adopted by the hydrologic modelers is simple: METRIC ET is quicker to generate and more accurate that previous methods. Previous methods of mapping ET for input to the model depend on mapping cropland, divining a nominal crop-area percentage for a county, then applying crop coefficients to the nominal breakout. This would yield a nominal value for potential ET by cell. METRIC ET, in contrast, is actual ET, not potential ET; it does not use crop-type discrimination, does not require crop-land mapping, produces ET on a 30-meter cell, and can be aggregated directly to the model cell. Figures 7.0-1a and 7.0-1b illustrate the difference.

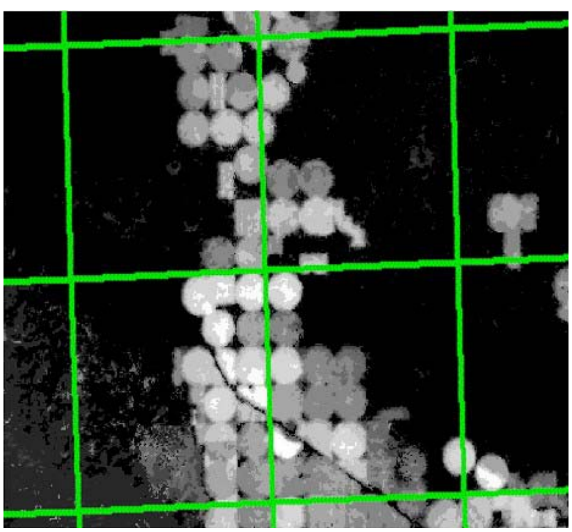


Figure 7.0-1a. Grid cells of the Eastern Snake Plain hydrologic model overlaid on seasonal ET from METRIC.

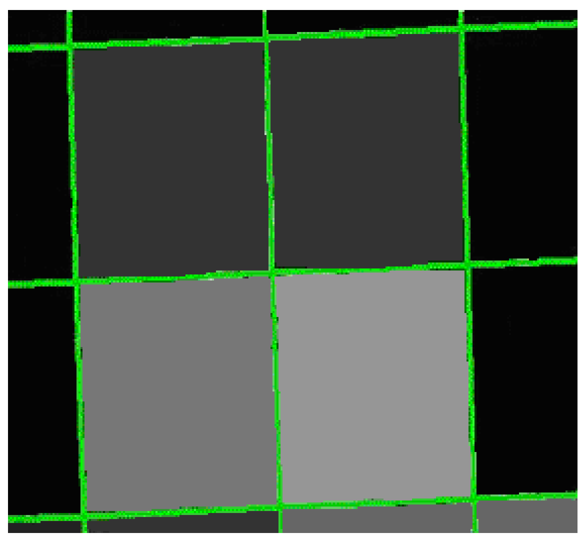


Figure 7.0-1b. Conceptual illustration of the same area covered in Fig. 7.0-1a using the ‘old’ method of deriving ET.

METRIC ET has been used as input in calibrating the Eastern Snake Plain Aquifer Model, for the Treasure Valley Hydrologic Model, and for several applications of the

MIKE Basin model. The MIKE Basin model, which is an ArcView extension, is particularly suited for METRIC input.

IDWR has run or is running the MIKE Basin model using METRIC ET data in five areas: the Stanley Basin, the East Fork of the Salmon River, the Lemhi River basin, the Pahsimeroi River basin, and in the Thousand Springs area along the Snake River.

Application	Location	Product	Impact
Hydrologic Modeling IDWR	Eastern Snake River Plain	ET for hydrologic model water budget	• Increased accuracy • Decreased cost
Hydrologic Modeling IDWR	Lower Boise River Valley	ET for hydrologic model water budget	• Increased irrigation efficiency • Protection of endangered species
Hydrologic Modeling IDWR	Lemhi River Basin	ET for hydrologic model water budget	• Increased irrigation efficiency • Protection of endangered species
Hydrologic Modeling IDWR	Stanley Basin	ET for hydrologic model water budget	• Increased irrigation efficiency • Protection of endangered species
Hydrologic Modeling IDWR	East Fork of the Salmon River Basin	ET for hydrologic model water budget	• Increased irrigation efficiency • Protection of endangered species
Hydrologic Modeling IDWR	Pahsimeroi River Basin	ET for hydrologic model water budget	• Increased irrigation efficiency • Protection of endangered species
Hydrologic Modeling IDWR	Thousand Springs Reach of the Snake River	ET for hydrologic model water budget	• Optimized water distribution • Support for conjunctive management
Water use Data IDWR	Southern Idaho	Statistics on irrigation water use by county and by hydrologic unit for 2000	• Better understanding of Idaho's use of irrigation water

Table 7.0-1. The application, location, product and impacts of METRIC ET for the user community.

8.0 Product Development and User Support Issues

The operational use of EOS data requires an operational data source. None of the EOS platforms is operational with the exception of Landsat. The Landsat platform is ideal for applications involving water rights. The pixel size is excellent for aggregation to the farm fields in Idaho. The scene size is large enough to make processing practical. The repeat cycle is less than optimal, although when there were two operational Landsats the repeat cycle was very good. The speed with which acquisitions become available is excellent. The infrastructure for scene distribution is excellent. The automatic archiving all US scenes makes data availability excellent. The cost of Landsat is reasonable. And the promise of data continuity is in statute. No other EOS platform meets all these standards.

The pending demise of the Landsat program is very problematic for IDWR support. Some business processes at IDWR can use METRIC ET without any significant process modification. Those business processes are Water Planning and Hydrology, which are using METRIC ET operationally. The problem is with business processes that involve water rights and regulatory processes.

The Water Distribution Section is responsible for monitoring ground water pumping. The monitoring process is complex, involving agreements with two power companies for annual records on power consumption by thousands of irrigation wells. The power meters from which those data are recorded are regularly calibrated in an annual program.

Work done for Phase 3 demonstrated that ET from METRIC can be used successfully as a surrogate for the power consumption approach to pumpage monitoring. In fact, the METRIC data are faster, cheaper, and more accurate. Nevertheless, the METRIC approach has not replaced the power consumption approach. Three factors have inhibited the adoption of METRIC by the Water Distribution Section through the Phase 4 work.

The first reason is the cost of modifying the present business process. This includes both the adoption of the new method as well as the abandonment of the old method in which there is considerable investment. Adopting a new method of doing business can be slow in government – there is no personal incentive for change, and there is in place a method that is understood.

The second reason is the uncertainty about the future of Landsat program. IDWR will not make the investment to in a new process without the assurance that the necessary data (Landsat) will continue to be available.

The third reason is need to finish delineating place-of-use polygons in order to apply the method uniformly throughout the monitoring area. The schedule for finishing these polygons is set for 2006.

It cannot be emphasized enough that IDWR water managers will not commit to modifying their operational business processes to incorporate data from a non-operational platform. EOS data must be cheap, easy to obtain, reliable, and available indefinitely into the future. Users will not build operational applications based on research data without the assurance of data continuity.

9.0 Cooperation with Other Infomarts

Representatives affiliated with the Battelle Northwest Laboratories have held discussions with IDWR about potential IDWR input to the watershed component of their InfoMart. These discussions have been in the form of a conference call and two face-to-face meetings.

The IDWR involvement would center around IDWR's need to better understand the hydrologic contribution to the Snake Plane Aquifer of the surrounding tributary valleys. The rivers flowing out of nearly all those valleys are ungauged. A remote sensing method that would help estimate runoff from the tributary valleys would be a useful addition to the Snake Plane Aquifer hydrologic model.

10.0 Potential Activities for Phase V

Activities will take three directions: 1) transferring RS and GIS technology to local water delivery organizations; and 2) exploring the relationship between the MODIS ET product and METRIC; and 3) working with the USBR to integrate METRIC into their western water decision support systems.

The purposes of the first activity are to 1) build a user base for remote sensing products, 2) improve the efficiency of water delivery in Idaho, and 3) function as a pilot project for USBR activities with other local water delivery organizations in the Northwest. The purpose of the second activity is to better understand the how MODIS data can be substituted for Landsat data. The purposes of the third activity are to 1) increase the METRIC user community; 2) transfer a efficient water-resource technology to the largest water-resource management agency in the Unites States.

Outline of Synergy Phase 5 Proposed Work
Idaho Department of Water Resources
University of Idaho

I. Components:

1. METRIC analysis
2. Pilot for BOR
3. Work with Local Water Delivery Organizations

II. Study areas:

1. 40/30
    a. Overpass dates already processed for year 2000
    b. MODIS ET comparison with METRIC
2. Entire Columbia Basin
    a. MODIS ET and METRIC ET
    b. Evaluation by BOR
        i. Inclusion in ET toolbox
        ii. AWARDS DSS

III. Functions

1. METRIC Analysis
    a. compare MODIS ET product with METRIC
        i. process coincident MODIS/Landsat dates for year 2000
        ii. Aggregate Landsat to
            1. watersheds
            2. MODIS pixels
        iii. compare MODIS ET with METRIC ET
            1. For year 2000
            2. For other processed years
    b. for entire Columbia Basin
        i. availability of MODIS data
            1. number of cloud-free scenes
            2. number of days needed to get entire basin cloud free; i.e. maybe no cloud free days, but using parts of 3 consecutive days, can get consistently cloud-free mosaic, and never need more than 4 consecutive days
        ii. processing issues for MODIS/METRIC

iii. limits of interpretability

IV. Work with Local Water Delivery Organizations

a. Goal: to evaluate operational use of METRIC by new group of users
b. Organizations
    i. Twin Falls Canal Company
    ii. Idaho Ground Water Users Assoc.
    iii. J. R. Simplot, Inc.
c. Workshops for task development
    i. Definition of user needs and goals
    ii. Develop tasks for evaluation process
    iii. User education on METRIC
    iv. Data Transfer
    v. User evaluation
    vi. Review
d. Use existing year 2000 ET data

IV. Overall Phase Goals:

1. Understand better how METRIC scales from Landsat to MODIS
2. Evaluate the MODIS ET product as an ET source for large areas
3. Evaluate the differences between METRIC and MODIS ET
4. Evaluate METRIC and MODIS as source of ET for large areas
5. Demonstrate utility of METRIC ET for US Bureau of Reclamation

V. Potential cooperators:

1. IDWR
2. University of Idaho (Rick Allen)
3. USBR
4. University of Montana (Steve Running)

11.0 References

Allen, R.G., M. Tasumi, and I.L.Torres; 2004; Investigations and refinements to the METRIC satellite image processing procedure for more accurate prediction of evapotranspiration from desert and cities; University of Idaho Research Report to the Idaho Department of Water Resources; 20 pps.

Allen, R.G., A. Morse, and M.Tasumi. 2003. Application of SEBAL for Western US Water Rights Regulation and Planning. Proc. Int. Workshop on Use of Remote Sensing of Crop Evapotranspiration for Large Regions. 54th IEC Meeting of the International Commission on Irrigation and Drainage (ICID), Montpellier, France, Wednesday, 17 September, 2003. 13 pages. On web at http://www.kimberly.uidaho.edu/water/montpellier/index.html

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Morse, A.., W.J. Kramber, M. Wilkins; R.G. Allen, M. Tasumi; 2003; Evapotranspiration by Land Cover Class computed Using Landsat TM Data and SEBAL; Proceedings of the 2003 International Geoscience and Remote Sensing Symposium; Toulouse, France

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Appendix A List of publications and Presentations

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Morse, A.; 2003; Idaho Synergy: How a Landsat-Based Evapotranspiration Model Helps Administer Idaho Water Rights; presented at the 83rd annual Meeting of the American Meteorological Society; Long Beach, CA

Tasumi, M., R. G. Allen, R. Trezza, J. L. Wright. 2003. Satellite-based energy balance to assess within-population variance of crop coefficient curves, ASCE *Journal of Irrigation and Drainage Engineering* (accepted)

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Appendix B List of Undergraduate/Graduate Student Involvement

The University of Idaho supported four students during Synergy Phase 4. Three of the students were at the Ph. D. level, with two Ph.D.s being awarded for work performed specifically for Synergy. Those receiving Ph.D.s were Ricardo Trezza, (PhD awarded by Utah State University) for "Evapotranspiration using a satellite-based surface energy balance with standardized ground control," and Masahiro Tasumi for "Progress in operational estimation of regional evapotranspiration using satellite imagery."

Maria Gloria Romero, working through Utah State University is writing a dissertation titled, "Daily evapotranspiration estimation from instantaneous values by means of evaporative fraction and reference evapotranspiration fraction." This work is also directly from Synergy.

Brock Dille is working on a BS at the University of Idaho. He is working on general GIS analyses of ET for irrigated areas.

Synergy Phase 4 supported two Idaho State University students at the M.S. level: Zach Lifton, and Ben McMahan. Lifton worked on the accuracy verification, and McMahan validated the METRIC conversion to IDRISI.

Appendix C Inventory of Software and Equipment Purchased

1) Dell Precision™Workstation 650 Intel® Xeon™ Processor, 2.66GHz, 512K Cache

$9,012.93

Date:	Thursday, May 01, 2003 3:50:25 PM CST
Catalog Number:	84 RC957159
1st Processor:	Intel® Xeon™ Processor, 2.66GHz, 512K Cache 65T26 - [221-1716]
2nd Processor:	Intel® Xeon™ Processor, 2.66GHz, 512K Cache PR26 - [311-2276]
Intel Hyper-Threading:	Hyper-Threading feature preset to "ON." Can be disabled/enabled in BIOS. HYPER - [460-7163]
Memory:	2GB,DDR266 SDRAM Memory,ECC (4 DIMMS) 2GE4 - [311-2290]
Keyboard:	Entry Level, PS/2, No Hot Keys E - [310-1609]
Mouse:	PS/2,Dell, 2 button w/no scroll WS - [310-8300]
Monitor:	Dell UltraSharp™ 2000FP 20 inch Flat Panel Monitor (20.0 inch vis) 2000FP - [320-1524]
Graphics Cards:	nVidia, Quadro4 900XGL, 128MB, VGA/DVI (dual monitor capable) 900XGL - [320-0574]
First Hard Drive:	146GB Ultra 320 SCSI, 1 inch (10,000 rpm) for PERC3 146S10P - [340-7596]
2nd Hard Drive:	146GB Ultra 320 SCSI, 1 inch (10,000 rpm) 146S10A - [340-7608]
3rd Hard Drive:	146GB Ultra 320 SCSI, 1 inch (10,000 rpm) 146S10A - [340-7608]
4th Hard Drive:	146GB Ultra 320 SCSI, 1 inch (10,000 rpm) 146S10A - [340-7608]
4th Hard Drive Bracket:	4th Hard Drive Bracket, SCSI, Gray BR4HDS - [310-1600]
CD-ROM, DVD:	4X DVD+RW/+R AND 16XDVD-ROM,DVD Decode/Sonic SE(for Professional Authoring) DRWDV4X - [313-1516]
Optional SCSI/RAID:	PERC320,RAID5,Parity,for 4 SCSI Hard Drives 4P35 - [340-7619]
Floppy Drive:	3.5 inch 1.44MB Floppy Drive 3 - [340-3736]
Operating System:	Windows® XP Professional Version with CD using NTFS WXP - [420-1533]
Speakers:	Internal Chassis Speaker,Dell INTSPK - [313-1469]
Cables:	2nd IDE Cable RMSDIIN - [310-2847]
Hardware Support:	3Yr Parts + Onsite Labor (Next Business Day) U3OS - [900-6212] [900-7370]
Installation Services:	No Installation NOINSTL - [900-9987]

2. Eleven 72.3 GB disk drives for a Dell PowerVault storage device.